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EVALUATION OF EMISSIONS FROM SELECTED UNINVENTORIED SOURCES IN THE STATE OF CALIFORNIA

FINAL REPORT

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ABSTRACT

The California Air Resources Board, with the assistance of local and regional air pollution control districts, maintains an extensive statewide emission inventory of criteria pollutants. This document ranks the emissions from 47 emission source categories that are not currently inventoried. A primary objective of this study was to evaluate the significance of these uninventoried sources. A second objective was to develop methodologies for refining and spatially disaggregating emission estimates from the significant source categories. Source categories emitting volatile organic compounds were the primary focus of this study. Sources of ammonia (manure wastes) and particulate matter (wind blown dust) were also considered.

The project was conducted in two phases. In the first phase, preliminary emission calculations for the 47 source categories were prepared. A ranking process was then developed and used to rank each emission source category considered. The results of the first phase are documented in an interim report.*

The second phase of this project, presented in this document, focused on eight source categories that were selected from the ranking process. For these eight source categories, methods for refining and spatially disaggregating the preliminary emission estimates were developed. A detailed methodology for calculating statistical confidence intervals for the refined emission estimates was also developed and applied.

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LIST OF ACRONYMS AND ABBREVIATIONS

APCD	- Air Pollution Control District
ARB	- California Air Resources Board
CALTRANS	- California Department of Transportation
CO	- Carbon monoxide
DHS	- California Department of Health Services
ft	- Feet
gal	- Gallon
EITAC	- Emission Inventory Technical Advisory Committee
gm	- Gram
hp	- Horse power
hr	- Hour
HAR	- Hydrogeologic assessment report
kg	- Kilogram
lb	- Pound
IC	- Internal combustion
m	- Meter
mg	- Milligram
mi	- Miles
mph	- Miles per hour
N	- Nitrogen
NH_3	- Ammonia
NMHC	- Nonmethane hydrocarbons
NO_x	- Nitrogen oxides
OH	- Hydroxide radical
PAH	- Polynuclear aromatic hydrocarbons
PM	- Particulate matter
PM_{10}	- Particulate matter less than 10 microns in diameter
POTW	- Publicly Owned Treatment Works
ppm	- Parts per million
ROG	- Reactive organic gas
SEDAB	- South East Desert Air Basin
SWRCB	- State Water Resources Control Board
SCAQMD	- South Coast Air Quality Managment District

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

SO_x	- Oxides of sulfur
sq	- Square
SWMB	- Solid Waste Management Board
TOG	- Total organic gas
TSP	- Total suspended particulate
ug	- Microgram
U.S.D.A.	- United States Department of Agriculture
U.S. EPA	- United States Environmental Protection Agency
VOC	- Volatile organic compound
yr	- Year
K	- Degrees Kelvin

1.0 INTRODUCTION

This document presents a summary of the emission source ranking that was performed for 47 source categories that are not currently included in ARB's statewide emission inventory. Table 1-1 presents a concise list of the source categories. The primary focus of this document is to present methodologies that can be used to refine and spatially disaggregate emissions from eight of the top ranked source categories.

1.1 Program Objectives

In performing this study, we were guided by two major objectives:

- To estimate the magnitude of emissions and determine the significance of uninventoried sources; and
- To develop appropriate techniques for estimating emissions from significant uninventoried sources.

Both objectives are consistent with ARB's long-term goal of reducing uncertainties in the statewide emission inventory of criteria and related pollutants.

1.2 Program Background

This study was conducted in two phases. Phase I examined 47 different emission source categories and calculated preliminary emission estimates. Each source category was ranked in decreasing order of emissions and its relative contribution to uncertainty in downwind ozone predictions. Results of the Phase I effort are documented in an interim report.

TABLE 1-1. SOURCE CATEGORIES CONSIDERED[a]

High Priority

Aircraft Refueling
Aesthetic Fireplaces
Boat Refueling
Bunker/Diesel Fuel Loading - Ships & Barges
Cooling Tower Drift
Exempt St. IC Engines
Illegal Hazardous Liquid Waste Disposal
Kerosene/Oil Loading - Marine Vessels
Livestock Wastes
Onshore Petroleum Seeps
Roofing Asphalt
Sanitary Sewers
Wind Erosion

Medium Priority

Domestic and Native Animal Wastes
Exempt Printing/Repro Equip
Major Building Ventilation Systems
Military Bases
Military and Commercial Ships in Transit
Misc. Crude Oil Trans., Stor., Spillage
Misc. Gasoline Trans., Stor., Spillage Standby St. IC Engine Testing

Low Priority

Abandoned Hazardous Waste Sites
Alcoholic Beverage Use
Auto Wrecking
Brewery Fugitive Emissions
Chemical Toilets
Cigarette Smoking
Concrete Coating Compounds
Liquid Waste Disposal Ponds
Misc. Methanol Trans., Stor., Spillage
Motor Oil Disposal
Offshore Petroleum Seeps
Org. Waste Evap. - Hazardous Landfills
Petroleum Spills - Offshore Platforms/ Ships
Restaurant Cooking - excludes deep fat frying and char broiling
Residential Cooking - excludes natural gas
Shut-in Oil Wells
TEOR - Fireflooding
Tanker Cargo Washing
Tanker Purging
Undocumented Abandoned Dumps
Vacuum Cleaning Trucks
Vegetative Sources

[a] Man-made petroleum seeps and nonresidential wood combustion (fireplaces and wood stoves) at Lake Tahoe and Mammoth Lakes were added to this list following review of the interim report.

From these 47 source categories, the following eight categories were chosen for further consideration in Phase II:

- Domestic and native animal waste;
- Exempt and standby stationary IC engines;
- Livestock waste;
- Nonresidential wood combustion (fireplaces and stoves) at Lake Tahoe and Mammoth Lakes;
- Organic waste evaporation from hazardous waste landfills;
- Roofing asphalt;
- Sanitary sewers; and
- Wind erosion.

The primary focus of the Phase II effort was to refine the emission factors and activity data (e.g., throughput, process rate, fuel consumption, etc.) for certain preliminary emission estimates calculated in Phase I and to provide the ARB with detailed methodologies that can be used to spatially disaggregate the resulting refined emission estimates to the District/air basin level.

The methodologies for refining the significant emission estimates provided in Sections 3 through 10 of this document have differing levels of detail, depending on the availability of data and information. Where the data were reasonably accessible, refined statewide emission estimates were calculated. Where county-by-county emission estimates would have to be calculated and summed to provide a statewide estimate, a methodology was developed that can be used to refine the preliminary emission estimate. Calculating refined emission estimates for these source categories was beyond the resources available for the second phase of this project. However, at a minimum, the following information is presented for all source categories:

- Definition of the source category;
- Methodology for developing activity data;
- Methodology for developing emission factors;
- Methodology for estimating emissions (including a discussion of the accuracy of the activity data and emission factors and a discussion of spatial and temporal variations); and
- TOG speciation data.

The TOG speciation data presented in the interim report are rough approximations and were developed for the purposes of ranking the emission source categories. As a part of refining the significant emission estimates, the most up-to-date and accurate speciation data are presented in this document. In some cases, these data are different than the profiles contained in the interim report. This difference reflects new data obtained after the submittal of the interim report.

1.3 Organization of the Document

The overall organization of the document is presented below:

- Section 2 presents a summary of the source category ranking and selection of emission source categories for refinement;
- Sections 3 through 10 present detailed methodologies that can be used to refine eight of the relatively significant emission estimates;

- Section 11 presents the methodology used to establish confidence intervals for the refined emission factors and activity data; and

- Section 12 presents a summary of recommendations; and

- Section 13 presents the bibliography.

2.0 PROGRAM SUMMARY

This section presents a summary of both the Phase I and II results. A summary of the emission source category ranking is presented in Section 2.1. The Phase II activities are summarized in Section 2.2, while Section 2.3 discusses the significant emission source categories that were not chosen for refinement.

2.1 Ranking of Preliminary Emission Estimates and Selection of Emission Source Categories for Refinement

We were requested to estimate emissions from 47 source categories that were divided into high, medium, and low priority categories. Our primary focus was on completing emission estimates for the high priority sources, with a lesser focus on the medium to low priority sources. The interim report prepared for this study documents the preliminary emission estimates. We were unable to determine emission estimates for the sources shown below.

Source Type	Priority	Emission Factors Identified?	Activity Data Identified?
1. Military and Commercial Ships in Transit	Medium	Yes	No
2. Brewery Fugitive Emissions	Low	No	Yes
3. Undocumented Abandoned Dumps	Low	No	No
4. Abandoned Hazardous Waste Sites	Low	No	No
5. Chemical Toilets	Low	No	No
6. Unpermitted Oil Field Tanks	Low	(emissions estimated by ARB)	

In order to select source categories for further consideration, a quantitative ranking procedure was developed. Detailed results of the ranking procedure are presented in the interim report. A summary of these results is presented in Table 2-1. The quantitative ranking procedure ranked each source category based on the relative magnitude of the emissions, the photochemical reactivity of the emissions, and the relative uncertainty of the emissions. By taking into account other considerations such as ammonia, particulate matter, air toxics, and data availability, the following eight source categories were chosen for refinement (listed in alphabetical order):

- Domestic and native animal waste;
- Exempt and standby stationary IC engines;
- Livestock waste;
- Nonresidential wood combustion (fireplaces and stoves) in the Lake Tahoe and Mammoth Lakes areas;
- Organic waste evaporation from hazardous waste landfills;
- Roofing asphalt;
- Sanitary sewers; and
- Wind erosion.

Both ARB and the Emissions Inventory Technical Advisory Committee (EITAC) participated in selecting these emission source categories.

In general, these categories are the top-ranked emission sources and were thus chosen for further consideration in the second phase of this study.

TABLE 2-1. SUMMARY OF QUANTITATIVE RANKING[a]

Source	Ranking Factor A[b] (thousands)	Ranking Factor B[c] (thousands)
Vegetative sources	220,000	650,000
Liquid waste disposal ponds	6,100	31,000
Aesthetic fireplaces	1,900	7,600
Livestock wastes	890	2,700[e]
Sanitary sewers	310	1,600[e]
Exempt stationary IC engines	97	1,100[e]
Roofing asphalt	300	600[e]
Offshore petroleum seeps	80	400
Domestic/native animal waste	95	380[e]
Exempt printing	170	340
Residential cooking	60	300
Organic waste evaporation - hazardous landfills	67	270[e]
Restaurant cooking	47	240
Man-made seeps	48	240
Vacuum cleaning trucks	25	130
Miscellaneous methanol transfer, storage, and spillage	31	120
Onshore petroleum seeps	15	75
Motor oil disposal	16	64
Miscellaneous crude oil transfer, storage	12	60
Standby stationary IC engine test	19	57[e]
Military bases - nonpermitted	10	50
Cooling tower drift (refineries)	14	42
Shut-in oil wells	14	42
Major building ventilation systems	14	41
Tanker purging	12	36
Alcoholic beverage use	10	20
Wet process copiers	3.8	19
Illegal liquid hazardous waste disposal	1.5	7.5
Concrete coating compounds	2.5	7.4
Boat refueling	7.1	7.1
Miscellaneous gasoline transfer, storage	6.1	6.1
Nonresidential wood combustion[d]	5	5[e]
Bunker/diesel loading	1.9	3.7
Aircraft refueling	1.5	3.1
Cigarette smoking	1.3	2.6
Marine vessel loading	2.4	2.4
Teor - fireflooding	0.2	0.6
Petroleum spills - offshore	0.1	0.6
Auto wrecking	0.2	0.4

(Continued)

TABLE 2-1. (Continued)

Source	Ranking Factor A[b] (thousands)	Ranking Factor B[b] (thousands)
Military ships in transit	Not determined at this time	
Abandoned hazardous waste sites	Not determined at this time	
Chemical toilets	Not determined at this time	
Abandoned hazardous waste sites	Not determined at this time	
Chemical toilets	Not determined at this time	
Brewery fugitive emissions	Not determined at this time	
Undocumented abandoned dumps	Not determined at this time	
Unpermitted oil field tanks	Not determined at this time	
Tanker cargo washing	Negligible: emissions occur during purging	
Wind erosion[e]		

[a] The values presented here have been rounded to two significant figures.

[b] Ranking Factor A represents the TOG emissions weighted by an OH radical rate constant. The OH radical rate constant is a physical constant that describes the photochemical reactivity of hydrocarbon emissions. As this constant increases, the reactivity of the emissions also increases. See the revised interim report for more detail.

[c] Ranking Factor B represents the TOG emissions weighted by an OH radical rate constant and an uncertainty factor. All emission estimates were assigned an uncertainty factor ranging from one to five, with five indicating the most amount of uncertainty. See the revised interim report for more detail.

[d] Emissions calculated for Lake Tahoe and Mammoth Lakes only.

[e] Emission source categories chosen for refinement in the second phase of this study.

2.2 Summary of Refined Emission Estimates

The second phase of this study focused on developing detailed methodologies that can be used by the ARB to estimate emissions and spatially disaggregate the resulting estimates. Where the data were reasonable accessible, refined statewide emission estimates were calculated. Table 2-2 presents a summary of the refined statewide emission estimates.

Where county-specific estimates would have to be calculated and summed to provide a statewide estimate, a methodology was developed that can be used to refine the preliminary emission estimate. This is the case for exempt stationary and standby IC engines as well as organic waste evaporation from hazardous waste evaporation from landfills.

In the case of sanitary sewers, an extensive literature search and numerous contacts with various regulatory agency staff failed to identify sufficient information available to provide a methodology to refine the preliminary emission estimate. The EPA has reached this same conclusion. A joint two-year study with the EPA and the City of Cincinnati is now underway to study sewer emissions and generate data that will characterize this emission source category. The ARB is also beginning a field study for this emission source category in the Bay Area.

Establishing confidence intervals was an integral portion of developing the methodologies for refining the eight source categories selected for the second phase of this study. Often times, insufficient data are available to calculate statistical rigorous confidence intervals. In these instances, a methodology was developed and applied that relies on subjective judgements to estimate confidence intervals. This type of procedure is often necessary when the emissions to be estimated may not be from sources strictly comparable to the sources from which the data were obtained, or the measurement methods may not be strictly comparable. If either or both are sufficiently different,

TABLE 2-2. SUMMARY OF REFINED EMISSION ESTIMATES (TON/DAY)

Emission Source Category	TOG	ROG	CO	NO_x	PM	NH_3
Domestic and Native Animal Waste	95	29				35
Exempt Stationary and Standby IC Engines	a	a	a	a	a	
Livestock Waste	1,400	420				950
Nonresidential Wood Combustion[b]	c	0.6	4.1	0.08	0.7	
Organic Waste Evaporation from Hazardous Waste Landfills	a	a				
Roofing Asphalt	10	7			0.06	
Sanitary Sewers	d	d				
Wind Erosion					14,000[e]	

[a] Refined emission estimates were not generated for these emission source categories. Rather, detailed methodologies were developed that can be used to calculate emission estimates on a county-by-county basis and then summed to yield state totals. See text.

[b] Emission estimates for nonresidential fireplaces and wood stoves in the Lake Tahoe and Mammoth Lakes areas only.

[c] TOG emission factor not available.

[d] Insufficient data exists to refine the preliminary emission estimates.

[e] Emission estimate consists of 3,500 ton/day from agricultural lands, 10,000 ton/day from desert lands, and 92 ton/day from unpaved roads. The agricultural lands estimate does not account for the effects of irrigation and therefore may overstate the actual emissions.

the estimated mean value or range of estimated mean values for the emissions were adjusted by an "applicability factor" to attempt to account for the lack of comparability. The applicability factor is expressed as a percentage of the estimated value or of the midpoint of the range of estimated values. Enlargement of an estimated value, or range of estimated values, by an applicability factor is an attempt to express more accurately the size of the uncertainty of the stated level of confidence.

The type of subjective judgement described above was then used in conjunction with standard statistical procedures to determine confidence intervals. These procedures involved using the Student's t as well as the method of propagation of errors.

2.3 Significant Source Categories Not Chosen for Refinement

There are several potentially significant source categories that were not further considered in the second phase of this project. Each of these source categories is discussed briefly below.

2.3.1 Vegetative Emissions

Although vegetative reactive organic gas (ROG) emissions were estimated to be three times the current state inventory for anthropogenic sources, we did not pursue this source category in any greater detail. Three research efforts that we are aware of have shown that vegetative ROG emissions do not play as important a role in the formation of ozone in urban airsheds as the magnitude of the emissions might indicate. We believe there are three primary factors that contribute to this observation:

- The emissions tend to be located primarily near the sides and edges of urban areas;

- The emissions in some instances are located above the atmospheric mixed layer; and

- The emission density in an urban area is relatively low compared to anthropogenic point and area sources.

In an ozone controllability study for the South Coast Air Basin, a sensitivity analysis was performed to determine the effects that vegetative emissions have on ozone (Souten et al., 1980). Although 57 percent of the ROG emissions in the modeling grid were attributable to vegetation, removing the vegetative emissions had minimal impact on ozone predictions. Removing the vegetative emissions from the inventory reduced predicted ozone concentrations by only one to eight percent, depending upon the receptor location.

In a study for Kern County, it was found that the vegetative emissions are roughly equal to the anthropogenic emissions (Croes, 1986). The effect that vegetative emissions have on ozone calculations was determined by increasing the vegetative emissions by a factor of 4 (or a 400-percent increase). Modeling analyses at this much higher emission rate increased predicted ozone concentrations by only 8 to 20 percent.

In another study for the Bay Area, it was found that removing vegetative emissions from the modeling analyses decreased predicted ozone concentrations by approximately 17 percent (Perardi, 1986). Vegetative emissions accounted for approximately 35 percent of the ROG emissions. However, it should be noted that when control measures were applied to the anthropogenic sources so as to simulate achievement of the ozone standard, removing the vegetative emissions reduced the predicted ozone concentrations by 39 percent.

Furthermore, a statewide inventory, where local vegetative cover would be taken into account for each air basin would be extremely resource intensive. A significant level of effort is also needed to improve ROG emission factors for specific species of vegetation. Due to these considerations and coupled with the fact that vegetative emissions do not impact ozone formation in urban areas to the degree suggested by their magnitude, demonstrate why this source category was not considered in the second phase of this study. Project resources were focused on those sources that have not been studied as extensively as vegetative emissions.

2.3.2 Aesthetic Fireplaces

Although the category of aesthetic fireplaces was ranked high, ARB requested an evaluation of emissions from nonresidential wood combustion (fireplaces and stoves) in the Lake Tahoe and Mammoth Lakes areas for the second phase of this study. The ARB is currently compiling residential wood combustion statistics in another study.

2.3.3 Liquid Waste Disposal Ponds

The emission estimate developed for liquid waste disposal ponds includes emissions from oil field sumps. These sump emissions are included in the 1983 state inventory. There are currently very limited data available that could be used to improve the emission estimate for liquid waste disposal ponds once the oil field sump emissions are subtracted out.

The California Department of Health Services (DHS) and State Water Resources Control Board (SWRCB) are currently gathering additional information on the 562 liquid waste disposal ponds in California. As part of the permitting process, a hydrogeologic assessment report (HAR) must be filled out for each disposal pond. Telephone conversations with SWRCB indicate that the HARs should have sufficient information (e.g., size of ponds and types of chemical wastes disposed) to provide a much better estimate of emissions. However, HARs have not yet been received for all disposal ponds. It appears that these reports should be available sometime in late 1987. Consequently, it was decided to focus on other source categories in the second phase of this study since the HARs would not be ready in the time frame of this project.

2.3.4 Exempt Printing

Due to the complexity of this emission source category, exempt printing was not included in the second phase of the study. It was decided that more useful information could be obtained by focusing project resources on other source categories.

2.3.5 Residential and Restaurant Cooking

Although we have provided an emission estimate for residential and restaurant cooking, our confidence in this estimate is extremely low. Therefore, we do not recommend incorporating the estimates into the state inventory. Emission factors that were not available through the open literature must be developed for these sources.

2.3.6 Vacuum Cleaning Trucks

In order to better estimate emissions from vacuum cleaning trucks, emission factors for this source category will have to be established. The transfer of emission factors from other source categories introduces an unacceptable level of error for use in refined emission estimates. Further, adequate activity data which characterize the emissions from this source category do not exist. A survey of operators is needed to further define the type and amount of wastes hauled.

2.3.7 Miscellaneous Methanol

We found only limited data for miscellaneous methanol (transportation, storage, and spillage). The ranking factor presented in Table 2-1, in fact, is for windshield wiper fluid evaporation and not for the transportation, storage, and spillage of methanol. Because of the limited information that appears to be available, we decided not to spend any additional resources on this source category.

2.3.8 Offshore Petroleum Seeps

A rough approximation of the expected emissions from offshore petroleum seeps was developed from information and data contained in the open literature. This emission source category was not considered in the second phase of this project for two reasons. First of all, an extensive literature search was performed and only limited data were found. Therefore, original field data gathering would be necessary to provide a better estimate of emissions. Such an effort is outside the scope of this project. Secondly, the emissions from this source category are dynamic and irregular due to seismic activity. Therefore, project resources were focused on other source categories that could be quantified and included in the statewide emission inventory.

3.0 DOMESTIC AND NATIVE ANIMAL WASTE

This source category characterizes the emissions of fugitive hydrocarbons and ammonia (NH_3) from the natural decomposition of domestic (pets) and native animal wastes. Statewide emission estimates are presented along with methodologies for spatial disaggregation.

3.1 Activity Data for Domestic and Native Animals

3.1.1 Domestic Animal Activity Data

Activity data for cat and dog populations in California were developed from three census reports published in the Journal of Veterinary Medical Association (Schneider 1975a, 1975b; Franti and Kraus, 1975). This literature includes results of surveys conducted for three counties in California: Alameda, Contra Costa, and Yolo. A summary of the the pet to human population ratios is presented below:

County	Dogs (per 1,000 people)	Cats (per 1,000 people)
Alameda	122	83
Contra Costa	167	111
Yolo	220	133

This data indicates the proportion of households owning pets is higher in rural/suburban Yolo County than in suburban/urban Contra Costa County, which in turn exceeds that of urban Alameda County. Activity data for Yolo, Contra Costa, and Alameda counties were used to calculate total rural, suburban, and urban pet populations, respectively.

Using 1986 human population estimates (State of California 1986), counties were grouped by population size. Rural counties were considered to have less than 200,000 people, suburban counties were considered to have between 200,000 and 800,000 residents, and urban counties were considered to have populations greater than 800,000. Total rural, suburban, and urban human populations were then determined and used to calculate pet populations in the state, using the pet to human population ratios presented above. Table 3-1 illustrates this calculation.

3.1.2 Native Animal Activity Data

A recent check list of species in California includes 47 amphibians, 77 reptiles, 542 birds, and 3,214 mammals for a total of 3,830 species (Laudenslayer, 1983). The California Department of Fish and Game only estimates population numbers for game and/or rare animals. Population estimates are available for bear, elk, mountain lion, wild pig, deer, bighorn sheep, and pronghorn antelope. Table 3-2 summarizes the 1986 population estimates for these animals.

3.2 Emission Factors for Domestic and Native Animal Waste

A literature search was conducted at the University of California at Davis Health Sciences Library in an attempt to identify data and information that could be used to develop emission factors on a per animal basis. In this literature search, we were only able to identify manure production rate data for dogs, bears, and lions. We assumed, therefore, that the emission factors developed for livestock wastes could be applied to native animals. The transfer of these data is discussed briefly below.

Extensive information on nitrogen content, in addition to manure production rates, were found in the literature for mink and livestock wastes. These data, in conjunction with the livestock TOG emission factors identified for the interim report, were used to estimate emissions for Domestic and Native Animal Waste. In general, emission factors were transferred according to animal weight. Refinement of this transfer could possibly be achieved by also accounting for differences in digestive tracts and food types. For example, the ammonia emission factors presented here for dogs and cats are developed from mink data to account for their carnivorous diets. Similar considerations could be used to refine the other emission factors.

TABLE 3-1. ACTIVITY DATA CALCULATIONS FOR DOMESTIC DOG AND CAT POPULATIONS IN CALIFORNIA

Species	Pet Ratio[d] (per 1,000 people)	Human Population[e] (million people)	Number of Pets (millions)
Dogs			
Urban counties[a]	122	18	2.2
Urban/suburban counties[b]	167	6.5	1.1
Suburban/rural counties[c]	220	2.2	0.48
TOTAL			3.8
Cats			
Urban counties[a]	83	18	1.5
Urban/suburban counties[b]	111	6.5	0.72
Suburban/rural counties[c]	133	2.2	0.29
TOTAL			2.5

[a] Counties with 800,000 or more inhabitants.

[b] Counties with 200,000 to 800,000 inhabitants.

[c] Counties with less than 200,000 inhabitants.

[d] Sources: 1) Schneider, 1975a and 1975b.
2) Kraus, 1975.

[e] Based on 1986 statistics.

TABLE 3-2. 1986 WILDLIFE POPULATION ESTIMATES

Animal	Estimated Population
Wild Pig	80,000 - 100,000
Mountain Lion	5,100 - 6,000
Elk	7,000 - 8,000
Deer	750,000 - 1,250,000
Pronghorn Antelope	7,300
Mountain Sheep	
California Bighorn	300
Peninsular Bighorn	1,000
Nelsons Bighorn	3,000
Black Bear	10,000 - 15,000

Source: Cook, 1987.

A summary of the emission factor development is presented in Table 3-3; Table 3-4 presents the emission factors. More detail regarding the development of the livestock emission factors is presented in Section 5.0 and Appendix A.

3.3 Emission Estimates for Domestic and Native Animal Waste

Table 3-5 summarizes the emission estimates developed for domestic and native animal waste based on the calculation methodologies described above. These emissions are expected to occur evenly throughout the year with little temporal variation. A discussion of the relative accuracy of the emission estimates is provided in Sections 3.3.1 and 3.3.2.

The spatial distribution of emissions from domestic animals corresonds to human demographics. Therefore, the methodology used to develop the emission factors for this emission source category can also be used to disaggregate the emission totals.

Spatial disaggregation of the native animal emission estimates is expected to be more resource intensive. The California Fish and Game Department maintains herd maps for the native animals listed in Table 3-4 (Grifith, 1988). The resolution of these maps is dependent on animal species. For example, the location of endangered species, tule elk, antelope, and big horn sheep herds are known with a high degree of accuracy. Deer, wild pig, mountain lion, and bear locations can be identified as well from maps maintained by the Fish and Game Department, but not with the same accuracy. Accessing this information would require the help of the Fish and Game staff.

3.3.1 Development of Confidence Intervals for Domestic Animals

There was insufficient information available to calculate statistically rigorous confidence intervals for the activity data. It is our subjective judgement, based on a review of the published literature, that the

TABLE 3-3. SUMMARY OF DOMESTIC AND NATIVE ANIMAL WASTE EMISSION FACTOR DEVELOPMENT

Animal Type	Parameter	Information Source for Emission Factors	Development of Statistical Confidence Intervals
Domestic Dogs	TOG	Emission factor transferred from livestock sheep.	Assumed TOG emission factor has an accuracy of $\pm$ 50% (with 95% confidence) and has an applica-bility of 50% for domestic dogs.
	NH_3	Emission factor transferred from mink to account for carnivorous diet. Assumed 50% of nitrogen excreted by a mink volatilizes as NH_3. See Appendix A for more details.	Statistical confidence inter-val calculated for mink nitrogen data. Assumed this data is 50% applicable to domestic dogs.
Domestic Cats	TOG	Emission factor transferred from poultry (based on animal size).	Assumed TOG emission factor has an accuracy of $\pm$ 50% (with 95% confidence) and has an applica-bility of 50% for domestic cats.
	NH_3	Emission factor transferred from mink to account for carnivorous diet. Assumed 50% of nitrogen excreted by a mink volatilizes as NH_3. See Appendix A for more details.	Statistical confidence interval calculated for mink nitrogen data. Assumed this data is 85% applicable to domestic cats.
Wild Pigs	TOG	Emission factor transferred from livestock pigs.	Assumed emission factor has an accuracy of $\pm$ 50% (with 95% confidence) and has an appli-cability of 85% for wild pigs.

(Continued)

TABLE 3-3. (Continued)

Animal Type	Parameter	Information Source for Emission Factors	Development of Statistical Confidence Intervals
	NH_3	Emission factor transferred from livestock pigs. Assumed 50% of nitrogen volatilizes as NH_3.	Statistical confidence interval calculated for livestock pig nitrogen data. Assumed this data has an applicability of 85% for wild pigs.
Deer, Bear, and Antelope	TOG	Emission factor transferred from livestock sheep.	Assumed emission factor has an accuracy of $\pm$ 50% (with 95% confidence) and has an applicability of 50% for deer, bear, and antelope.
	NH_3	Emission factor transferred from livestock sheep. Assumed 50% of nitrogen volatilizes as NH_3.	Statistical confidence interval calculated for livestock sheep nitrogen data. Assumed this data has an applicability of 50% for deer, bear, and antelope.
Mountain Lion	TOG	Emission factor transferred from livestock sheep.	Assumed emission factor has an accuracy of $\pm$ 50% (with 95% confidence) and has an applicability of 50% for mountain lion.
	NH_3	Emission factor transferred from mink waste to account for carnivorous diet. Nitrogen as a percent of waste excreted was ratioed to lion waste generation to estimate total nitrogen excreted by lions. Assumed 50% nitrogen volatilizes as NH_3. See Appendix A for more details.	Statistical confidence intervals calculated for mink nitrogen data were adjusted up based on the ratio of the amount of waste excreted. Assumed this data has an applicability of 50% for mountain lion.

(Continued)

TABLE 3-3. (Continued)

Animal Type	Parameter	Information Source for Emission Factors	Development of Statistical Confidence Intervals
Elk	TOG	Emission factor transferred from livestock horses.	Assumed emission factor has an accuracy of $\pm$ 50% (with 95% confidence) and has an applicability of 50% for elk.
	NH_3	Emission factor transferred from livestock horses. Assumed 40% of nitrogen volatilizes as NH_3 based on horse data.	Statistical confidence intervals calculated for horse data. Assumed this data has an applicability of 50% for elk.
Native Sheep	TOG	Emission factor transferred from livestock sheep.	Assumed emission factor has an accuracy of $\pm$ 50% (with 95% confidence) and has an applicability of 85% for native sheep.
	NH_3	Emission factor transferred from livestock sheep. Assumed 50% of nitrogen volatilizes as NH_3.	Statistical confidence interval calculated for livestock sheep nitrogen data. Assumed this data has an applicability of 85% for native sheep.

TABLE 3-4. EMISSION FACTORS FOR NATIVE AND DOMESTIC ANIMAL WASTES (LB/YR HEAD)

Animal Type	Mean TOG Emission Factor	TOG Emission Factor Confidence Interval[a]	Mean NH_3-N Emission Factor	NH_3-N Emission Factor Confidence Interval[a]
Domestic Dog	12	0 - 24	1.6	0 - 3.6
Domestic Cat	2.6	0 - 5.2	1.6	0.30 - 3.0
Wild Pigs	58	20 - 96	43	34 - 51
Mountain Lion	12	0 - 24	6.9	2.3 - 12
Elk	84	0 - 168	54	5.1 - 102
Deer	12	0 - 24	10	2.7 - 17
Native Sheeps	12	4.2 - 20	10	5.8 - 12.4
Bear	12	0 - 24	10	2.7 - 17
Antelope	12	0 - 24	10	2.7 - 17

[a] 95 percent confidence intervals.

Source: See Table 7-3.

TABLE 3-5. EMISSION ESTIMATES FOR NATIVE AND DOMESTIC ANIMAL WASTES (TON/DAY)

Animal Type	Mean TOG Emissions	TOG Confidence Interval[a]	Mean NH_3-N Emissions	NH_3-N Confidence Interval[a]
Domestic Dog	62	0 - 160	8.6	0 - 24
Domestic Cat	8.9	0 - 22	5.7	0.8 - 13
Wild Pig	7.2	1.8 - 15	5.3	3.1 - 8.4
Mountain Lion	0.091	0 - 0.23	0.053	0.013 - 0.11
Elk	0.86	0 - 2.2	0.55	0.039 - 1.3
Deer	16	0 - 41	14	2.81 - 29
Native Sheeps	0.071	0.018 - 0.42	0.059	0.026 - 0.10
Bear	0.21	0 - 0.51	0.17	0.035 - 0.37
Antelope	0.12	0 - 0.31	0.10	0.21 - 0.22
TOTAL	95	1.8 - 240	35	7.0 - 76.5

[a] 90 percent confidence intervals.

[b] This total accounts for the species listed above. The actual emissions from this category are expected to be greater than this estimate due to other domestic animals whose populations are not monitored by the Department of Fish and Game.

pet population estimates are accurate within ± 25 percent (with 95% confidence) of the actual values. The applicability of the activity data is assumed to be 100 percent.

The emission factors used for domestic dogs and cats were transferred from mink and livestock data. Due to the transfer of this data, the emission factors are not 100 percent applicable. The assumed applicability for each species is summarized in Table 3-3.

3.3.2 Development of Confidence Intervals for Native Animals

The wildlife population activity data are derived from the state Fish and Game's wild life management estimates. We believe with 95 percent confidence that these estimates are accurate within ± 25 percent. The applicability of the activity data is assumed to be 100 percent.

All emission factors used for estimating native animal waste were transferred from data and information published for livestock waste. Due to the transfer of data, the livestock emission factors are not 100 percent applicable. The assumed applicability for each species is summarized in Table 3-3.

3.4 TOG Speciation of Domestic and Native Animal Waste Emissions

In our review of the published literature, no information was identified regarding hydrocarbon emissions from either domestic or native animal wastes. The best approximation at this time for TOG species profiles for this emission source category can be found under livestock waste in Section 5.0

4.0 EXEMPT STATIONARY AND STANDBY IC ENGINES

This emission source category covers emissions from stationary and standby diesel, natural gas, dual fuel (diesel and natural gas), and gasoline-powered IC engines that are exempt from regulation in the State of California. These engines are separate and distinct from utility engines that are currently included in the ARB's statewide emission inventory. However, some districts already include this emission source category in their inventories.

4.1 Activity Data for Exempt Stationary and Standby IC Engines

Conducting a thorough survey and examination of the number of stationary IC engines in California would require a detailed and rather involved technical effort. Such an effort was considered beyond the scope of this project. In 1979, the U.S. EPA estimated the number of stationary IC engines on a national basis (U.S. EPA, 1979). In this document, prepared for standards support and as an Environmental Impact Statement, the number of stationary IC engines were estimated for the following economic sectors:

- Oil and gas pipelines;
- Oil and gas production;
- General industrial (including construction);
- Electrical power generation; and
- Agriculture.

Table 4-1 summarizes the engine population estimates as presented by EPA. These estimates were generated from various market surveys, industrial contacts, and research reports. An indication of the basis for the population estimate is also provided.

An obvious concern regarding the EPA data is its age. Nevertheless, we have chosen to recommend these data and consider this information the most accurate and complete data available. To account for its age, these population estimates can be brought forward in time in much the same way as engineering economic data. For example, the EPA provides an estimate of the

TABLE 4-1. NATIONAL ESTIMATES OF STATIONARY IC ENGINES[a]

Category	Population[b] Units	Average Power hp	Load Factor	Annual Usage hr/yr	Basis of Estimate
DIESEL					
Oil and Gas Production					
Offshore drilling	675	350	0.8	2,000	AGA Market Study
Land drilling	3,050	350	0.8	2,000	AGA Market Study
Oil and Gas Transport	500	2,000	0.8	6,000	McGowin, Gas Facts
Electric Generation	400[c]	2,500	0.8	2,600	FPC, Diesel and Gas Power Costs
General Industrial and Agriculture					
Municipal water supply	2,100	120	0.75	3,000	AGA Market Study
Marine Nonpropulsive	15,000	100	0.5	3,500	Current Industrial Report, Industry contacts
Construction, small	50,000	50	0.5	500	
Miscellaneous, large[d]		750	0.5	100	
Construction, large	50,000	240	0.5	500	
Portable compressors[e]	90.000	75	0.5	500	
Welders	80,000	55	0.5	500	
Pumps	25,000	100	0.5	1,000	
Generator sets (standby)					
<50 kW	70,000	75	0.5	500	
50 kW - 400 kW	160,000	250	0.5	250	
500 Kw - 1,000 kW	30,000	750	0.5	100	

(Continued)

TABLE 4-1. (Continued)

Category	Population[b] Units	Average Power hp	Load Factor	Annual Usage hr/yr	Basis of Estimate
DUAL FUEL					
Oil and Gas Transport	Included in		0.8	6,000	McGowin, Gas Facts
Electric Generation	Diesel		0.8		FPC, Diesel and Gas Power Costs
NATURAL GAS[f]					
Agriculture	91,000	100	0.75	2,500	AGA Market Study
Oil and Gas Production					
Oil and gas well pumps	266,000	15	0.7	3,500	AGA Market Study
Secondary recovery	5,600	200	0.8	6,000	AGA Market Study
Well drilling	3,050	350	0.8	2,000	AGA Market Study
Plant processing	4,000	750	0.8	8,000	McGowin
Oil and Gas Industry					
Utility compressors[g]	4,500	2,000	0.9	6,000	Southwest Research Institute
	4,000	750	0.8	6,000	Southwest Research Institute
Electric Generation					
Commercial-institutional	450	200	0.45	4,000	AGA Market Study
Standy-by	2,000	100	0.9	50	AGA Market Study
Industrial on-site	1,500	300	0.6	4,000	AGA Market Study

(Continued)

TABLE 4-1. (Continued)

Category	Population[b] Units	Average Power hp	Load Factor	Annual Usage hr/yr	Basis of Estimate
General Industrial					
Industrial shaft power	2,900	200	0.75	5,000	AGA Market Study
Plant air	750	100	0.5	4,000	AGA Market Study
Air-conditioning	3,760	80	0.4	2,000	AGA Market Study
Commercial shaft power	600	2,000	0.6	1,000	AGA Market Study
Municipal					
water supply	2,100	120	0.75	3,000	AGA Market Study
waste treatment	1,740	400	0.45	4,000	AGA Market Study
GASOLINE					
Agriculture					
Misc. machinery[h]	400,000	30	0.5	200	Current Industrial Reports, Industry contacts
Irrigation	10,000	100	0.75	2,000	
General Industrial					
Generator Sets >5 kW	350,000	55	0.5	400	
Compressors	70,000	55	0.5	400	
Welders	180,000	55	0.5	400	
Miscellaneous	50,000	55	0.5	400	
Construction	40,000	150	0.5	500	
Small (<15 hp)	63,000,000	4.2	0.5	50	Current Industrial Reports

[a] Source: U.S. EPA, 1979.

[b] Annual production multiplies by life in years (based on estimated service life of 5,000 hours for diesel engines, 4,000 hours for gasoline engines, or as noted) to compute population.

(Continued)

TABLE 4-1. (Continued)

Footnotes (continued)

[c] Approximated, based on estimated population and annual usage.

[d] Applications include pumps, snow blowers, aircraft turbine starters, etc.

[e] Excludes mobile refrigeration units.

[f] Population estimates come from the AGA market study. Annual production is not estimated for this category since production has been changing rapidly, decreasing continuously since 1966. Therefore, an annual estimate of production would be misleading.

[g] Includes transport, distribution, gathering, and storage.

[h] Pull combines, balers, sprayers, dusters, etc.

number of engines in use in 1979 for oil and gas production. The 1979 population estimates can be brought forward in time by multiplying the population estimate by a ratio of 1979 oil and gas production to the oil and gas production of the year of interest.

A similar technique can be used to spatially disaggregate the engine population estimates. Rather than ratioing different values in time, ratios can be developed using geographic locations. Again as an example, the number of engines used for oil and gas production can be estimated for Kern County by determining the national oil and gas production and ratioing it to Kern County production. This ratio times the number of national engines yields an approximation of the number of engines in Kern County used for oil and gas production. Table 4-2 presents a series of reference materials that present activity data that can be used to update and spatially disaggregate engine populations.

4.2 Emission Factors for Exempt Stationary and Standby IC Engines

An inhouse literature search was used to identify representative emission factors for this source category. These emission factors, which are dependent upon fuel type, are presented in Table 4-3.

4.3 Emission Estimates for Exempt Stationary and Standby IC Engines

Phase I of this project used the data and information presented in Table 4-1 to estimate statewide emissions from this source category. In order to further refine the preliminary emission estimates, county-specific emission estimates must be calculated and then summed to provide a statewide estimate. This effort is beyond the resources available for this study. Therefore, a detailed methodology has been developed and presented here that can be used to refine the preliminary emission estimates.

TABLE 4-2. REFERENCE MATERIAL FOR SPATIAL DISAGGREGATION OF STATIONARY IC ENGINE POPULATIONS

User	Activity Data	Reference for National Data	Reference for State Data
Oil and Gas Industry			
Drilling	Oil exploration	Oil and Gas Journal	Annual Report of the State Oil and Gas Supervisor[a]
Pumps (production)	Primary oil production	Oil and Gas Journal	Annual Report of the State Oil and Gas Supervisor[a]
Secondary recovery	Secondary oil production	Oil and Gas Journal	Annual Report of the State Oil and Gas Supervisor[a]
Processing	Refinery production	Oil and Gas Journal	Annual Report of the State Oil and Gas Supervisor[a]
Pipelines (transport)	Gas transportation	Oil and Gas Journal	Annual Report of the State Oil and Gas Supervisor[a]
Electrical Generation			
Institutional	Population	U.S. Statistical Abstract[g]	California Statistical Abstract[f]
Industrial	Industrial employment	U.S. Statistical Abstract[g]	County Business Patterns[h]
Standby	Industrial employment	U.S. Statistical Abstract[g]	County Business Patterns[h]

(Continued)

TABLE 4-2. (Continued)

User	Activity Data	Reference for National Data	Reference for State Data
Agricultural			
Irrigation	Irrigated acres	Census of Agriculture[e]	Census of Agriculture[e]
Misc. machinery	Cropland harvested	Census of Agriculture[e]	Census of Agriculture[e]
Industrial			
Construction	Construction employment and dollar value	U.S. Statistical Abstract[g]	Statistical Abstracts for L.A.[c] Department of Finance[d]
Municipal water and waste treatment	Human population	U.S. Statistical Abstract[g]	California Statistical Abstract[f]
Marine nonpropulsive waste	Shipping traffic	Waterborne Commerce of U.S., Parts 1-4[b]	Waterborne Commerce of U.S., Parts 1-4[b]
Industrial Plant	Industrial employment	U.S. Statistical Abstract[g]	County Business Patterns[h]

[a] Prepared for the California Department of Conservation.

[b] Prepared for the Army Corps of Engineers

[c] This reference provides construction employment, which can be used to disaggregate national data to the state level.

[d] This state office maintains data on the value of nonresidential and residential construction. This data can be used to disaggregate state totals to the county/air basin level.

(Continued)

TABLE 4-2. (Continued)

Footnotes (continued):

[e] "1982 Census of Agriculture, Volume I, Part V," Bureau of the Census, U.S. Department of Commerce, Washington, DC.

[f] "California Statistical Abstract, 1986," California State Department of Finance.

[g] "Statistical Abstract of the United States, 1986," Bureau of the Census, U.S. Department of Commerce, Washington, DC.

[h] "County Business Patterns, 1984," Bureau of Census, U.S. Department of Commerce.

TABLE 4-3. EMISSION FACTORS FOR EXEMPT STATIONARY AND STANDBY IC ENGINES

	Emission Factor (gm/bhp)				
	NO_x	CO	TOG	PM	SO_x
Diesel engines	10	46	1.1	0.9	NA
Natural gas[b]	13	2	1.0	--	--
Gasoline[c]	5.24	218	7.18	--	--

[a] Source: ERT, 1982

[b] Source: Sharu, 1975

[c] Source: U.S. EPA, 1985

Once the number of engines per air quality management district (AQMD) has been determined, District rules should be used to identify the population of engines that qualify as exempt. Table 4-4 summarizes District rules for exempt status for 14 of the Air Pollution Control Districts in California. Emissions can then be estimated using the following equation:

Emissions = (# of engines)(emission factor)(operating hours)(load factor)

In our judgement, the estimation methodology outlined here will provide emission estimates that are within an order of magnitude of actual values.

The temporal distribution of emissions for oil and gas activities, general industrial activities (with the exception of construction), and electrical power generation is expected to be fairly uniform through the year. Seasonal variations for agriculture and construction are expected. These emissions will occur primarily during the nonwinter months.

4.4 TOG Speciation Data for Exempt and Standby IC Engines

Speciation of TOG emissions from exempt and standby IC engines must take into account the different types of engines. That is, the TOG speciation profile of a stationary diesel engine is quite different than a gasoline engine. TOG species profiles for natural gas and diesel engines are given in Tables 4-5 and 4-6. These are the most accurate and complete set of data available at this time. We were not able to identify a speciation profile for stationary gasoline engines.

TABLE 4-4. EXEMPTION REQUIREMENTS FOR STATIONARY IC ENGINES FOR SELECT AIR POLLUTION CONTROL DISTRICTS IN CALIFORNIA

Air Quality Management District	Applicable Rule	Date of Rule	Exemption Requirement(s)
Bay Area	Regulation 2, Rule 1	10/19/83	1. Internal combustion (IC) engines or gas turbines of less than 190 kilowatts (250 hp) output rating.
			2. Internal combustion (IC) engines directly used for agricultural operations necessary for the growing of crops, or the raising of fowl or animals.
			3. Internal combustion engines that are laboratory engines used in research or teaching programs.
			4. Internal combustion engines used solely as a source of standby power and that are operated less than 100 hours per year or 1) are only used for power when normal power line service fails, or 2) are only used for the emergency pumping of water.
Fresno County	202	6/82	1. Piston type combustion engines with a rating of 750 brake horsepower or less.
Imperial County	202	11/19/85	1. Piston type internal combustion engines with rated output of less than 350 horsepower.

(Continued)

TABLE 4-4. (Continued)

Air Quality Management District	Applicable Rule	Date of Rule	Exemption Requirement(s)
Kern County	202	6/1/87	1. Rating of 500 brake horsepower or less and located within the Southeast Desert portion of Kern County of the Western Kern County Field (the rating shall change to less than 50 brake horsepower for the Western Kern County Fields upon the finding by the Air Pollution Control Board that there had been four separated validated ozone exceedances between January 1, 1988 and December 31, 1990).
			2. Rating of 50 brake horsepower or less and located within the Central Kern County Field.
			3. All internal combustion engines used for agricultural operation necessary for the growing of crops, or the raising of fowl or animals.
Kings County	202	7/2/85	1. Any engine used to operate emergency standby equipment.
			2. Piston type internal combustion engines with a rating of 500 brake horsepower or less.
Monterey Bay Unified	201	1/25/87	1. Stationary piston type internal combustion engines of 100 or less brake horsepower, or are operated less than 60 hours per year for

(Continued)

TABLE 4-4. (Continued)

Air Quality Management District	Applicable Rule	Date of Rule	Exemption Requirement(s)
			testing and are only used for power when normal powerline service fails or are used only for the emergency pumping of water.
Sacramento County	201	11/20/84	1. Internal combustion engines used on other than vehicles for transporting passengers or freight, and fired with natural gas or liquefied petroleum gas or those having 16 liters (976 cubic inches) cylinder displacement or less and fired with diesel oil or gasoline.
			2. Equipment used exclusively in the growing of agricultural crops, or in the commercial raising of fowl or other animals.
San Bernardino County	219	10/8/76	1. Piston type internal combustion engines with a rating of 500 brake horsepower.
San Diego County	11	9/26/84	1. Any combination of piston-type engines at one source, with a total maximum power input of less than 500 brake horsepower.
			2. Piston-type engines of greater than 500 brake horsepower which were installed before August 1, 1980.
			3. Any combination of piston-type engines for which construction commenced before April 5, 1983 provided all engines in the combination are less than 500 brake horsepower.

(Continued)

TABLE 4-4. (Continued)

Air Quality Management District	Applicable Rule	Date of Rule	Exemption Requirement(s)
San Luis Obispo County	213	7/5/77	1. Piston type internal combustion engines.
Santa Barbara County	201	6/81	1. Piston type internal combustion engines.
South Coast	219	9/4/81	1. Piston type internal combustion engines with a rating of 500 break horsepower or less.
Stanislaus County	202	undated	1. Piston type internal combustion engines with a rating of 750 brake horsepower or less.
Ventura County	23	12/86	1. Internal combustion engines used exclusively for frost protection or emergency service.
			2. Piston driven internal combustion engines used on oil drilling or work-over rigs, for driving air pumps at sewage treatment facilities, or for driving irrigation pumps.
			3. Internal combustion engines having a maximum design power rating of less than 50 brake horsepower.
			4. Piston driven internal combustion engines which are operated less than 200 hours per year, and which are used only to provide emergency electrical power or for emergency pumping of water.

RADIAN CORPORATION

TABLE 4-5. TOG SPECIES PROFILE FOR NATURAL GAS IC ENGINES

Species Name	Weight Percent
Isomers of Hexane	0.02
Isomers of Heptane	0.04
Isomers of Octane	0.02
Isomers of Nonane	0.01
Isomers of Decane	0.02
Isomers of Butene	0.26
Isomers of Pentane	0.13
C9 Olefins	0.04
C10 Olefins	0.02
Methane	76.64
Ethane	13.99
Ethylene	0.63
Propane	2.91
Propene	1.69
Acetylene	0.32
N-Butene	1.00
Iso-Butane	0.43
Isobutylene	0.02
T-2-Butene	0.13
CIS-2-Butene	0.02
N-Pentane	0.13
1-Pentene	0.01
Trans-2-Pentene	0.01
2-Methyl-2-Butene	0.01
3-Methyl Pentane	0.02
Hexane	0.02
Heptane	0.02
Octane	0.02
Nonane	0.01
N-Decane	0.01
N-Undecane	0.01
Cyclohexane	0.01
2,4-Dimethylpentane	0.01
Cyclopentane	0.02
Methylcyclohexane	0.02
Methylcyclopentane	0.04
1-Heptene	0.01
Octene	0.01
1-Nonene	0.01
2,2-Dimethylbutane	0.01
3-Methylhexane	0.01
3-Methylheptane	0.02
Formaldehyde	0.81
Acetaldehyde	C.03

(Continued)

TABLE 4-5. (Continued)

Species Name	Weight Percent
Isobutyraldehyde	0.02
Isomers of Xylene	0.02
C3/C4/C5 Alkylbenzenes	0.01
C10 Aromatic	0.01
Benzene	0.11
Toluene	0.04
Ethylbenzene	0.01
O-Xylene	0.01
M-Xylene	0.01
1,3,5-Trimethylbenzene	0.02
1,2,4-Trimethylbenzene	0.01
O-Ethyltoluene	0.01
M-Ethyltoluene	0.01
1,2,3-Trimethylbenzene	0.01
2-Methyl-1-Pentene	0.02

Source: Oliver and Peoples, 1985.

TABLE 4-6. TOG SPECIES PROFILE FOR STATIONARY DIESEL IC ENGINES

Species Name	Weight Percent
Ethylene	28.70
Propylene	17.30
Butene	13.40
1,3-Butadiene	7.00
Acetylene	11.30
Methane	11.60
Ethane	2.80
Benzene	7.90

Source: U.S. EPA, 1980. Data Confidence III "Average - based on data which seem reasonable and should be more or less representative of the population."

5.0 LIVESTOCK WASTE

This emission source category characterizes fugitive hydrocarbon emissions from the natural decomposition of farm animal manures. Ammonia emissions are also evaluated for this category. The specific livestock included in this emission source category are cattle, horses, sheep, poultry, and pigs.

5.1 Activity Data for Livestock Waste

Basic animal populations are available from the California Crop and Livestock Reporting Service. Activity data for beef and dairy cattle as well as the number of hogs on farms in California were taken from this data source for the year 1986. To further distinguish between dairy and beef cattle, certain assumptions were necessary. The California Crop and Livestock Reporting Service estimates there were approximately 5 million cattle in California in 1986. They do not provide an indication of what fraction of these cattle were beef or dairy. However, they do report that 1,030,000 dairy cattle and 950,000 beef cattle calved in 1986. The ratio of these two numbers was applied to the total number of cattle in California to estimate the number of beef and dairy cattle.

Poultry populations were taken from the 1982 census of Agriculture's Poultry Inventory and Sales. Horse and sheep population data were taken from the 1982 Census of Agriculture's Sheep and Horses Inventory and Sales. Table 5-1 summarizes the livestock inventory data available for the state of California.

In the case of livestock waste, it is important to further identify the location and number of livestock in feedlots. Feedlots represent a concentrated emission source in comparison to livestock kept on pasture or rangeland. The Bureau of Agricultural Statistics does not tract the number of cattle on feedlots by county, only by agricultural district. According to the Bureau of Agricultural Statistics, approximately eight percent of the

TABLE 5-1. LIVESTOCK POPULATION ESTIMATES

	Number of Animals
Cattle[a]	
Beef cattle	2,400,000
Dairy cattle	2,600,000
Poultry[b]	
Laying hens	39,456,033
Broiler chickens	23,858,777
Turkeys	5,187,215
Ducks, geese, and other poultry	2,703
Horses[c]	
Horses	129,310
Sheep[c]	
Sheep and lambs	1,214,585
Pigs[a]	
Hogs on farms	145,000

[a] 1986 population estimates from the California Crop and Livestock Reporting Service.

[b] 1982 population estimates from the Census of Agriculture's Poultry Inventory and Sales.

[c] 1982 population estimates from the Census of Agriculture's Sheep and Horses Inventory and Sales.

cattle in the state are kept on feedlots (Akan, 1987). Imperial Valley District (comprised entirely of Imperial County) has the largest number of cattle on feedlots at 73 percent. The Bureau of Agricultural Statistics maintains similar county-by-county statistics for the other livestock.

Using Dun's Market Identifiers® (a publicly available computerized database), we identified approximately 46 cattle feedlots in the State of California. In addition, there are five and ten feedlots for hogs and sheep/goats, respectively. A complete listing from this database, or a similar one, could be used in the spatial disaggregation of livestock emissions.

5.2 Emission Factors for Livestock Waste

To refine the emission factors used in the preliminary emission estimates, a literature search was conducted at the University of California at Davis Health Sciences Library. We also contacted the staff of the Animal Science Departments of UC Davis and UC Riverside. From the various reports, studies, reviews, and telephone contacts that were pursued, we found that the following information is generally available for each livestock species:

- Mass of feces produced per animal;
- Water content of feces;
- Total solids content of feces;
- Volatile solids content of feces;
- Nitrogen content of feces;
- Ammonium (NH_4) content of feces; and
- Elemental inorganic constituents of feces.

Volatile solids is a term used in manure management to describe the total organic content of feces. Manure is placed in a muffle furnace and heated for a specific amount of time to remove all organic matter. A gravimetric analysis is then used to determine the weight of inorganic matter in the feces.

We identified no literature that described organic gas emissions from livestock excrement. A literature search that focused on odors and odor control for livestock waste could possibly identify some data that could be used to better characterize livestock organic gas emissions. In lieu of any new data, we used the same emission factors that were used to calculate the preliminary emission estimates. These are the same emission factors used by the South Coast AQMD (Halberg, 1984).

Sufficient data were identified and used to refine the livestock ammonia emission factors. A summary of the ammonia emission factor development is presented in Table 5-2. As can be seen, we relied extensively on the data presented by Overcash (1983). Other data presented in the literature indicate similar values to those presented by Overcash and support the use of these data. Overcash presents a summary of manure characteristic data for a wide variety of species from over 400 literature references. Therefore, we chose to rely on the Overcash data because sufficient data were presented from which to calculate statistical confidence intervals.

The ammonia emission factors presented in Table 5-3 characterize the emissions that result from the natural decomposition of animal excrement. As a result of this decomposition, it was necessary to make certain assumptions regarding the percentage of total nitrogen that is converted and emitted as ammonia.

Ammonia is emitted to the atmosphere as a natural component of the nitrogen cycle. Complex organic nitrogeneous compounds are decomposed to a number of simpler compounds such as amino acids. Soil bacteria and certain fungi then convert amino nitrogen to ammonia in a process known as ammonification. This ammonia can then react with carbon dioxide and water present in the soil to form ammonium salts such as ammonium carbonate. Finally, nitrification takes place where certain soil bacteria oxidize the ammonia of the ammonium salts to nitrite (NO_2^-) or nitrate (NO_3^-). This is the form in which inorganic nitrogen is utilized by higher plants.

TABLE 5-2. SUMMARY OF LIVESTOCK AMMONIA EMISSION FACTOR DEVELOPMENT

Animal Type	Nitrogen Data Source(s)	Determination of NH_3 Emission Factor
Dairy and Beef Cattle	Overcash, 1983	Data presented by Gasser (1980) Adriano et al. (1974) and Luebs et al., (1973) indicates that approximately 50% of nitrogen excreted from cattle is present in the urine. This nitrogen is reported to be "easily" converted to NH_3 within a short period time. Therefore, it was assumed that 50% of the nitrogen excreted volatilizes as NH_3.
Chickens	Overcash, 1983	Most of the nitrogen in poultry manure is in the form of uric acid, a simple organic compound that is rapidly converted to ammonia (Meek, 1975). Overcash (1983) presents data showing that 9.2% of total nitrogen is excreted as ammonium (NH_3). Therefore, it was assumed that 90% the total nitrogen excreted volatilizes as NH_3.
Turkey and other Poultry	Overcash, 1983	Total nitrogen data presented as percent of waste generation. Therefore, 98% confidence intervals were calculated for percent of nitrogen in waste and waste generation per animal. Confidence intervals were combined to yield total nitrogen excreted per animal at 96% confidence. Based on chicken data, we assumed that 90% of total nitrogen excreted volatilizes as NH_3.

(Continued)

TABLE 5-2. (Continued)

Animal Type	Nitrogen Data Source(s)	Determination of NH_3 Emission Factor
Pigs	Meek, 1975; Overcash, 1983; and Cass et al., 1982	Overcash (1983) presents data that indicates 50% of the total nitrogen volatilizes as NH_3. Therefore, the NH_3 emission factor assumes that 50% of the total nitrogen excreted volatilizes as NH_3.
Horses	Overcash, 1983	Forty percent of nitrogen excreted from horses is in urine (Overcash, 1983). Based on cattle data, nitrogen contained in the urine is easily converted to NH_3. Therefore, the emission factor for horses assumes that 40% of total nitrogen excreted volatilizes as NH_3.
Sheep	Overcash, 1983	We assumed that 50% of the nitrogen excreted volatilizes as NH_3 based on cattle, horse, and pig data.

TABLE 5-3. EMISSION FACTORS FOR LIVESTOCK ANIMAL WASTES (LB/YR HEAD)

Animal Type	Mean TOG Emission Factor[a]	TOG Emission Factor Confidence Interval[b]	Mean NH_3-N Emission Factor[c]	NH_3-N Emission Factor Confidence Interval[d]
Beef Cattle	160	80 - 240	100	75 - 125
Dairy Cattle	160	80 - 240	130	110 - 150
Pigs	58	29 - 87	43	40 - 46
Horses	84	42 - 126	52	31 - 76
Sheep	12	6 - 18	10	8 - 12
Turkey and other Poultry	2.4	1.2 - 3.6	1.9	1.2 - 2.7
Broiler Chickens	2.4	1.2 - 3.6	0.79	0.72 - 0.90
Laying Chickens	2.4	1.2 - 3.6	1.6	1.4 - 1.8

[a] Source: Halberg, 1984.

[b] 95 percent confidence intervals based on an assumed accuracy of $\pm$ 50%.

[c] Source: See Table 7-11.

[d] Statistical confidence intervals calcualted using Equation 8-5.

Ammonia accumulation in the soil depends on rate of generation and loss of ammonia to the atmosphere. The rate of ammonia release is greatest when the manure-soil mixture is first moistened (Meek, 1975). A number of researchers have reported that ammonia emissions tend to increase during the drying of moist manure (data summarized by Luebs et al., 1973). This suggests, therefore, that ammonia emissions will be at a peak during spring and early summer as moistened manure dry out.

With the exception of livestock sheep, sufficient information was identified in the literature to estimate the percentage of total nitrogen that can be converted to ammonia. Typically, this is the nitrogen contained in urine. We then assumed that this ammonia is emitted to the atmosphere. Table 5-2 summarizes the development of the livestock emission factors; the actual factors are presented in Table 5-3. Appendix A presents the detailed calculations.

5.3 Emission Estimates For Livestock Waste

Using the activity data and emission factors described above, we calculated livestock emissions on a statewide basis (see Table 5-4). Without any specific data indicating otherwise, the TOG emissions are expected to occur evenly throughout the year with little temporal variation. Research data have shown that ammonia emissions increase after manure has been wetted and allowed to dry. This suggests that livestock ammonia emissions in California will be greatest in the spring and early summer as moist manures dry out from the winter rains (see Section 5.2). A discussion of the relative accuracy of emission estimates is presented below.

Very little information is available regarding the accuracy of the livestock inventories. For this document, we have assumed these population estimates are accurate to within $\pm$ 25 percent (with 95 percent confidence). With respect to applicability, activity data have not been approximated by an indirect measurement technique. That is, specific information regarding livestock populations is directly available. Therefore, these population data are 100 percent applicable to the source category.

TABLE 5-4. EMISSION ESTIMATES FROM LIVESTOCK WASTES (TON/DAY)

Animal Type	Mean TOG Emissions	TOG Confidence Interval[a]	Mean NH_3-N Emissions	NH_3-N Confidence Interval[a]
Dairy Cattle	570	214 - 1,068	460	290 - 668
Beef Cattle[b]	530	197 - 986	330	180 - 510
Pigs	12	4.5 - 22	8.5	6 - 11
Horses	15	5.3 - 26	9.2	4 - 17
Sheep	20	7.4 - 37	17	10 - 25
Laying Chickens	130	49 - 244	86	57 - 120
Broiler Chickens	78	29 - 147	26	18 - 37
Turkey and other Poultry	17	6.4 - 32	14	6.4 - 24
TOTAL	1,372	513 - 2,560	950	570 - 1,410

[a] 90 percent confidence intervals.

[b] Approximately 451,000 cattle were kept on feed lots in 1986. With an estimated 2,400,000 beef cattle, approximately 19 (451,000/2,400,000) percent of these emissions, therefore, result from feed lots.

There is insufficient information available to calculate rigorous statistical confidence intervals for the TOG emission factors. The confidence intervals presented in Table 5-4 assume that the emission factors have an accuracy of ± 50 percent (with 95% confidence).

For the ammonia emission factors, confidence intervals were calculated for the total nitrogen data presented in the literature. These confidence intervals were then used in the emission calculations. The confidence intervals do not account for the assumptions regarding the percentage of total nitrogen that is converted and emitted as ammonia.

As with the activity data, the emission factors were developed for individual species with no data transfer. Therefore, the emission factors were considered 100 percent applicable.

5.4 TOG Speciation Data for Livestock Emissions

Much of the data presented in the literature for animal wastes focuses on the mass of solids produced, ammonia content, and percent volatile solids. As such, there is limited information available regarding the speciation of TOG emissions from livestock waste. Table 5-5 presents a summary of volatile compounds that have been identified in decomposing animal wastes.

The EPA's Volatile Organic Compound Species Data Manual (EPA, 1980) provides a profile for decomposing animal waste (see Table 5-6). We were also able to identify data that illustrate the concentrations of some volatile compounds in liquid chicken manure. These data are presented in Table 5-7. These same data reportedly resemble the TOG species emitted from pig manure (Gasser, 1980).

TABLE 5-5. VOLATILE COMPOUNDS IDENTIFIED IN DECOMPOSING ANIMAL WASTES[a]

Type of Animal Waste	Class	Common Name Formula
Poultry, swine, cattle	Sulfides	hydrogen sulfide
Poultry	Sulfides	methyl sulfide
	Mercaptans	methyl mercaptan
		ethyl mercaptan
		n-propyl mercaptan
Cattle	Thioethers	dimethyl sulfide
		diethyl sulfide
Poultry, swine, cattle	Inorganic	ammonia
Poultry, swine	Aliphatic	methyl amine
Poultry, swine, cattle	Amines	ethyl amine
Cattle		trimethyl amine
Poultry, swine		triethyl amine
Poultry	Heterocyclic amines	benzo(b)-pyrols (indole)
		3-methyl-indole (skatole)
Poultry, swine	Alcohols	ethanol
		n-propanol
		iso-propanol
		n-butanol
		iso-butanol
		iso-pentanol
	Aldehydes	formaldehyde
		acetaldehyde
		propanaldehyde
		iso-butanaldehyde
		heptaldehyde
		valeraldehyde
		decaldehyde
Poultry, swine, cattle	Organic acids	acetic acid
		propionic acid
Poultry		2-methyl propionic acid

(Continued)

TABLE 5-5. (Continued)

Type of Animal Waste	Class	Common Name Formula
Poultry, swine, cattle		n-butynic acid n-valeric acid iso-valeric acid
Poultry		iso-butynic acid
Cattle	Acetates	propylacetate n-butylacetate

[a] Table is adopted from Ifeadi, 1972.

TABLE 5-6. TOG SPECIES PROFILE FOR ANIMAL WASTE DECOMPOSITION

Substance	Weight Percent
Acetone	2.0
Ethyl acohol	2.0
Isopropyl alcohol	2.0
Propyl acetate	2.0
Ethyl amine	1.0
Trimethyl amine	1.0
Methane	70
Ethane	20

Source: U.S. EPA, 1980. Data Confidence Level III - Based on data which seem reasonable and should be more or less representative of the population.

TABLE 5-7. CONCENTRATIONS OF SOME VOLATILE COMPOUNDS IN LIQUID CHICKEN MANURE

Substance	Concentration mg/kg
acetaldehyde	0.020
i-butyraldehyde	0.125
n-butyraldehyde	0.015
i-valeraldehyde	0.010
n-valeraldehyde	0.040
acrolein	0.165
crotonaldehyde	0.480
hydrogensulphide	2.0
methylmercaptan	0.590
ammonia	6,300
phenol	23
p-cresol	80
indole	2
skatole	10
acetic acid	3.5
propionic acid	3.8
i-butyric acid	2.0
n-butyric acid	6.6
i-valeric acid	5.3
n-valeric acid	1.4

Source: Gasser, 1980.

6.0 NONRESIDENTIAL WOOD COMBUSTION

In numerous communities throughout the United States, residential wood combustion is a significant source of air pollution that impairs air quality. For certain areas, such as mountain resorts, nonresidential wood combustion (stoves and fireplaces) may also be a significant source of emissions. For this reason, ARB requested Radian to evaluate nonresidential wood combustion emissions from the Mammoth Lakes and Lake Tahoe areas of California. The information gathered and presented here supplements the data and information that are currently being collected under another ARB study for the residential sector. Both ARB and the contractor performing the residential sector survey were contacted to ensure that there was no overlap between the two survey efforts.

6.1 Activity Data for Nonresidential Wood Combustion

Nonresidential wood combustion is comprised of three main categories: 1) nonresident housing units, 2) lobbies of lodges and motels, and 3) restaurants. Due to the large amount of data and information needed to calculate activity data for these categories, the following three approaches were evaluated:

- Obtaining the amount of wood consumed in the study area from local planning agencies;
- Obtaining the amount of wood cut in local forests from the U.S. Forest Service; and
- Obtaining wood sales data from grocery stores in the study area.

In the first two methods, we had hoped to obtain the total amount of wood consumed in the study areas. From the total, the residential sector could be subtracted out yielding the nonresidential portion. However, neither local planning agencies nor the Forest Service could identify the total amount of wood consumed in either geographic area. The Forest Service maintains records of the amount of wood cut and removed from each forest, but no records are kept that identify the destination of the wood. This is an important consideration, given that wood is cut in the Tahoe Forest and transported out of the area. Conversely, we identified instances where wood cut outside of the Tahoe basin was trucked in.

According to several property rental managers, most nonresidents obtain their fire wood from local grocery stores. Therefore, we contacted these local stores (and regional distribution centers) in an effort to obtain the amount of wood sold. Unfortunately, sales data are not cataloged in such a way that allows for the determination of local wood sales.

According to the Tahoe Regional Planning Agency, there were 8,347 occupied hotel and motel units (or rooms) in the basin in 1985 (Jordan, 1987). At the same time, the agency estimates that there were 9,323 visitor housing units (for comparison, there were an estimated 19,211 resident housing units). Assuming that most nonresident housing units have burning devices, wood consumption at hotels, motels, and restaurants (where there is typically only one burning device) is relatively small in comparison to the amount of wood consumed in nonresident housing units. Therefore, we chose to develop activity data for nonresident housing units only. (We accounted for the inaccuracy of neglecting motels/hotels and restaurants in the uncertainty analysis in Section 6.3.)

An extensive telephone survey was conducted to develop the following data needed to estimate the amount of wood consumed for nonresident housing units in each study area:

- The number of units burning wood;
- The frequency of occurrence for each burning device (e.g., fire places versus high efficient wood stoves); and
- The average amount of wood consumed per burning device.

Using the Hotel and Motel Index published by Murdoch Magazines, each property manager (including condominium managers) listed in the index was contacted to determine if their rental units contain burning devices, the number of such units, the type of burning devices, and the amount of wood consumed. Table 6-1 presents a summary of the the telephone survey results for both study areas.

As the survey progressed, it became evident that only a few property managers supply their tenants with wood. As a result, we contacted over 37 different property managers in the Lake Tahoe area to obtain 11 estimates of wood consumption per rental unit. Wood use data were found to be more readily available from the property managers of the Mammoth Lakes area. A qualitative discussion of the quality of this data is presented in Section 6.3.

For Lake Tahoe, the survey data were used in conjunction with the housing data compiled by the Tahoe Regional Planning Agency to estimate a mean wood use of 5,600 cords/year. For Mammoth Lakes, housing statistics are not available. Therefore, we relied solely on the telephone survey to obtain the number of nonresident burning devices and the mean wood consumption per device. These survey data yield a mean consumption rate of 4,700 cords per year.

6.2 Emission Factors for Nonresidential Wood Combustion

Due to the recent concern regarding wood combustion emissions in the United States, there have been numerous research efforts that have evaluated the emissions from fireplaces and wood stoves. Rather than perform a detailed literature search to compile emission factors, we choose to use the emission factors listed in AP-42 (U.S. EPA, 1985). The emission factors that are listed in AP-42 are a compilation of emission factors that have been reported in the literature, including the measurements made by Kosel for the ARB in 1980. Table 6-2 presents these emission factors.

TABLE 6-1. SUMMARY OF NONRESIDENTIAL WOOD COMBUSTION TELEPHONE SURVEY

	Number of Property Managers Contacted	Number of Rental Units with Burning Devices	Number of Property Managers Providing Wood Use Estimates	Average Amount of Wood Consumed per Unit (cords)
Lake Tahoe Basin[a]	37	3,200[b]	11	0.6
Mammoth Lakes	14	2,500	5	1.7

[a] For this study, the Lake Tahoe Basin is defined by the natural geographic boundaries of the lake (the City of Truckee is not included). Furthermore, rental units in both California and Nevada are included.

[b] Number of units managed by 37 property managers contacted. In comparison, the Tahoe Regional Planning Agency estimates there were 9,323 visitor housing units in 1985.

TABLE 6-2. EMISSION FACTORS FOR RESIDENTIAL FIREPLACES[a]

Pollutant	Emission Factor lb/ton of wood[b]	Emission Factor Ratings[c]
Particulate matter	28	C
Sulfur oxides	0.4	A
Nitrogen oxides	3.4	C
Carbon monoxide	170	C
Nonmethane hydrocarbons	26	D

[a] Source: AP-42 (U.S. EPA, 1985).

[b] Based on tests burning primarily oak, fir, or pine with moisture content ranging from 15-30 percent.

[c] All emission factors listed in AP-42 are given a letter ranking that ranges from "A" to "F". Where there are numerous data available that accurately describe the emissions from a particular emission source type, the emission factor is given an "A" ranking. Conversely, where the data is scarce, or there is some question about the representativenous of the data, the emission factor is given a rank of "E" or "F".

Virtually every property manager contacted in the telephone survey indicated that their rental units are equipped with fireplaces rather than wood stoves. An insignificant number of wood stoves were identified. Therefore, emission factors developed exclusively for fireplaces were used to estimate emissions. (We accounted for this inaccuracy in our uncertainty estimates as discussed below.)

6.3 Emission Estimates for Nonresidential Wood Combustion

Table 6-3 presents the emission estimates calculated for the Lake Tahoe and Mammoth Lakes areas. For Mammoth Lakes, the amount of wood consumed per rental unit was found to be much higher (1.7 vs. 0.6 cords/yr) than for Lake Tahoe. This difference appears to be the result of more property managers in the Mammoth Lakes area supplying their tenants with free wood than in Lake Tahoe. It should also be noted that the emission estimates presented for Lake Tahoe include both the California and Nevada sides. Approximately 4,000 cords are consumed on the California side as compared to 1,600 cords on the Nevada side.

Temporally, the emissions from nonresidential wood combustion are expected to occur primarily during the ski season. In normal years, the ski season ranges from December to March. A discussion of the confidence of these emission estimates is provided below.

Two components comprise the activity data: the number of burning devices and the amount of wood burned per device. There are four potential sources of error in the activity data:

- We have assumed that all visitor housing units in the Lake Tahoe area have burning devices. This assumption is consistent with the survey results, but it is unlikely that all of the 9,323 visitor housing units have fireplaces.

TABLE 6-3. NONRESIDENTIAL WOOD COMBUSTION ESTIMATES FOR LAKE TAHOE AND MAMMOTH LAKES[a]

	PM	NO_x	CO	ROG
Lake Tahoe[b]				
Mean emission estimate	130	16	800	120
90% confidence interval	8.4-390	1.0 - 48	52 - 2,400	3.4 - 410
Mammoth Lakes[c]				
Mean emission estimate	112.7	13.7	684	105
90% confidence interval	24.5 - 256	3.0 - 31.1	150 - 1,560	9.8 - 267

[a] Emission estimates based on activity data collected from property managers of nonresidential rental units. A cord of wood was assumed to weigh 1.65 tons. Emission factors were obtained from U.S. EPA (1985). All estimates are in tons per year.

[b] Estimates based on 5,600 cords of wood burned per year.

[c] Estimates based on 4,700 cords of wood burned per year.

- It is possible that the wood consumption rate (cords/yr unit) is biased high for Lake Tahoe. Approximately 20 percent of the property managers contacted had information on wood consumption rates. Several of these property managers supply their tenants with wood. We expect higher wood consumption rates occur where the wood is supplied for free in comparison to those units where the tenant must supply the wood. Furthermore, it should be noted that in several rental units that offer fireplaces, the burning of wood logs is prohibited. Tenants are only allowed to burn compressed sawdust logs (this appears to be a result of insurance requirements).

- As indicated previously, wood consumption for hotel/motel lobbies and restaurants was not included in the survey.

- For Mammoth Lakes, we relied on the telephone survey to identify the number of rental units with burning devices. The Hotel and Motel Index does not contain a complete list of property managers in the study area. We contacted the publishers of the index to confirm this suspicion. They agreed that the index is not all inclusive, but free listings are available to hotel, motel, and condominium mangers who want to list in the index. Therefore, it is reasonable to assume that if a property manager is aware of the index, he or she would list their facility. In addition, our telephone contacts in the Mammoth Lakes area suggests that the vast majority of the managers were contacted.

To account for the factors listed above, we assumed that the activity data (cords of wood per year) have an applicability of 80 percent. Confidence intervals for the amount of wood burned per device were computed using equation 11-5.

All emission factors listed in AP-42 are given a letter ranking that ranges from "A" to "F". Where there is numerous data available that accurately describe the emissions from a particular emission source type, the emission factor is given an "A" ranking. Conversely, where the data is scarce, or there is some question about the representativeness of the data, the emission factor is given a rank of "E" or "F". We translated these letter rankings into quantitative values by assuming that each letter represents a 20 percent increment. For example, an "A" ranking was assumed to indicate a 95-percent confidence interval of ± 20 percent. A "D" ranking, the lowest rank given to any of the fireplace emission factors, represents a confidence interval of ± 100 percent.

6.4 TOG Speciation Data for Wood Combustion

Two research studies were identified that present data that can be used to develop TOG species profiles for wood combustion. Both of these references present data for wood stoves (see Table 6-4). We were unable to identify TOG species profiles for fireplaces. Due to operating characteristics, TOG species profiles for stoves could be significantly different from fireplaces. Stoves are often operated under starved air conditions (through the use of a damper), resulting in lower combustion temperatures than a fireplace. This temperature difference is expected to affect both the quantity and types of hydrocarbons emitted.

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TABLE 6-4. TOG SPECIES PROFILES FOR WOOD BURNING STOVES

	Weight Percent
<u>Data Source 1</u>[a]	
methane	62.0
ethane	4.5
ethylene	15.0
propane	0.80
propene	1.2
butene	0.23
iso-butane	0.04
ethyl alcohol	9.26
benzene	6.3
unidentified	0.59
<u>Data Source 2</u>[b]	
methane	69.0
ethane	0.78
ethylene	1.9
propane	0.59
propylene	1.1
C_6-C_8[c]	0.68
formaldehyde	4.8
acetaldehyde	4.7
propionaldehyde	7.8
acetone	3.9
C_4 carbonyls[d]	4.9

[a] Source: Adapted from Allen et al., 1985.

[b] Source: Adapted from Kamens et al., 1984.

[c] Weight percent calculated assuming C_6 through C_8 hydrocarbons are equivalent to heptane.

[d] Weight percent calculated assuming C_4 carbonyls are equivalent to acetaledhyde.

7.0 ORGANIC WASTE EVAPORATION FROM HAZARDOUS WASTE LANDFILLS

There has been an increased concern about the impact of volatile emissions from hazardous waste landfills. These emissions affect air quality by acting as precursors to ozone and also presenting a possible carcinogenic risk to the human population surrounding the landfill.

In this report, we have evaluated ROG emissions resulting from the evaporation of hazardous organic wastes from Class I and Class II landfills in California. Class I disposal sites receive all waste types. Class II landfills may accept hazardous wastes under special conditions, in addition to nontoxic substances, and waste not capable of significantly impairing the quality of usable waters.

7.1 Activity Data for Organic Hazardous Waste Evaporation from Landfills

Short of emissions testing, there are two viable methods that can be used to develop refined emission estimates for this source category. Either a modeling approach or a surface flux (emission factor) approach can be used. Both of these methods have been well studied and evaluated by the U.S. EPA. An excellent summary of these methods is provided by Balfour et al. (1985). Due to the complexity of these methods, refined emissions were not calculated. The material that follows is a discussion of the surface flux method--the easier of the two methods. It is possible that more accurate emission estimates could be calculated with the modeling approach, but the data requirements for the model are much more rigorous.

The activity data that correspond to the flux or emission factor values are the surface area of the landfill. A complete list of the Class I and Class II landfill sites in California is available from the Toxic Substances Control Division of the Department of Health Services (DHS). This list includes the addresses and phone numbers for each facility, as well as a description of the type of waste disposed of at these facilities.

Personal communication with DHS established that the area used for landfill at each facility in California is public knowledge and can be obtained either by contacting the regional offices of DHS or by contacting the landfill sites directly.

7.2 Emission Factors for Organic Hazardous Waste Evaporation from Landfills

Emission factors specific to the type of waste disposed in a landfill are presented in Table 7-1. The emission factors were developed from actual emission flux rate data collected at various hazardous waste landfills nationwide (Balfour et al., 1985). A description of each landfill tested is given below.

- Site 2, Active Landfill. The landfill contains four active cells, but only one was tested for emissions. The tested cell contained solids from the following manufacturing processes: acrylonitrile, acetone cyanohydrin, lactic acid, tertiary butylamine, and iminodiacetic acid.

- Site 4, Active Chemical Landfill. This landfill is divided into five cells containing heavy metals, flammable solids, general organics, and PCBs/pesticides, respectively. Wastes containing greater than five percent free fluid, including air, are not accepted.

- Site 5, Landfill 10. Flux measurements were taken from three different cells: flammable, toxic, and organic. Specific wastes received by each cell are not specified.

To obtain the most accurate emission estimates, the type of waste disposed in a particular landfill should be determined and used in conjunction with the emission factor that best approximates the type of waste disposed. If the type of waste is unknown or is a combination of many compounds, the average of Table 7-1 should be used.

TABLE 7-1. SUMMARY OF AVAILABLE ORGANIC HAZARDOUS WASTE EMISSION FACTORS[a,b]

Landfill	Classification	Sample Number[c]	Mean Emission Factor[d] (lb ROG/ft^2 year)	Confidence Interval 95% (lb ROG/ft^2 year)
2	Active landfill	1	0.0058	0.0034, 0.0089
		2	0.0084	0.0044, 0.013
4	Active chemical landfill	1	0.048	0.023, 0.086
10	Active landfill Flammable cell	1	0.043	0.013, 0.13
		2	0.061	0.031, 0.32
		3	0.053	0.024, 0.86
10	Active landfill near toxic cell	1	0.012	0.025, 0.22
		2	0.017	0.11, 0.25
10	Active landfill Organic cell	1	0.11	0.05, 0.15
		2	0.90	0.36, 1.50

[a] Source: Adapted from W.D. Balfour et al., 1985.

[b] Values presented as NMHC.

[c] Measurements vary by sampling technique (i.e., transect or flux chamber) and sampling location.

[d] Based on the speciation data summarized in Table 7-2.

7.3 Emission Estimates for Organic Hazardous Waste Evaporation from Landfills

Calculating a refined statewide emission estimate for this category requires developing site-specific emission estimates and then summing these estimates for a statewide total. Developing these data for each landfill was beyond the resources for this study. Therefore, a detailed methodology is provided here that can be used by the ARB to refine the preliminary emission estimates.

The data required to estimate TOG emissions from organic hazardous waste landfills includes:

- An up-to-date list of the Class I and Class II landfills in California including the area being used for landfill and the types of waste present at each facility; and

- Emission factors specific to the type of waste being landfilled.

Once these data have been collected, the emission estimates for each facility can be calculated by multiplying the individual landfill areas by the emission factors appropriate to the type of waste being landfilled in that area. As mentioned in the previous section, if the types of waste in a particular site is unknown or complex, the average emission factor developed from Table 7-1.

The characteristics of the emissions resulting from the evaporation of organic hazardous waste from landfills are site specific and not easily predicted. Some of the factors affecting these emissions include the physical and chemical properties of waste and soil, the age of the waste, and the current meteorological conditions. Also, environmental regulations continue to affect the types of waste that can be landfilled.

Ninety-five percent confidence intervals were determined for the emission factors at the time of their inception. A Monte Carlo simulation of the pooled QA/QC experimental data were used to calculate the 95 percent confidence intervals in Table 7-1.

To evaluate the variability of the emission factors presented in Table 7-1, we calculated a mean and 95 percent confidence interval by treating each emission factor in the table as a single data point. The mean emission rate is 0.15 pounds of TOG per square foot per year with a 95 percent confidence interval of zero to 0.35. We recommend using this average and confidence interval when specific information about the waste material is unknown.

In general, we expect the emissions from hazardous waste landfills to be fairly uniform throughout the year. The phenomena that may affect the temporal resolution of the emission estimate include wind velocity, ambient pressure, rain fall, and temperature. Although these climatic conditions may affect the emission levels, there is insufficient information available at this time to determine temporal variations.

7.4 TOG Speciation of Organic Hazardous Waste Evaporation Emissions

Approximate TOG speciation profiles were developed from the emission factor data. An approximate profile for each type of landfill is presented in Table 7-2. Section 7.2 summarizes the types of waste received by each landfill.

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TABLE 7-2. TOG SPECIATION PROFILES FOR ORGANIC HAZARDOUS WASTE EVAPORATION EMISSIONS[a]

Species[b]	Weight Percent[c]				
	Active Landfill	Active Chemical Landfill	Flammable Cell	Near Toxic Cell	Organic Cell
Paraffins	49	24	13	15	4
Olefins	32	16	5	5	1
Total aromatics	16	42	60	50	93
Total halogenated HC	<1	18	20	29	<1
Total NMHC	97	100	98	99	98

Source: Adapted from Balfour et al., 1985.

[a] The wastes received by each landfill are summarized in Section 7.2.

[b] More detailed speciation data were not presented.

[c] Calculation based on weight of carbon emitted.

8.0 ROOFING MATERIALS

The two classes of materials used in roof manufacturing are roofing asphalt and roofer's pitch. Roofing asphalt is derived from crude petroleum oil and is composed primarily of paraffin, naphthene, and aromatic hydrocarbons. Roofer's pitch, on the other hand, is a condensation by-product from the carbonization of coal during coke production. It is composed primarily of high molecular weight ring structures.

Roofing material may either be applied directly to the top of a building, resulting in what is called a built-up roof, or it may be manufactured into tar felts or paper. The manufacture of felts and paper is not included in this emission source category.

Roofing materials may either be applied cold in solvent mixes, or they may be heated in a kettle and applied hot. Hydrocarbon emissions from cold asphalt result from the release of volatile compounds in the mixture.

The hydrocarbon emissions from hot asphalt result from thermal cracking and vaporization of low-boiling-point hydrocarbon oils during heating in the kettle. According to Puzinauskas (1979), thermal gradients within the asphalt kettle lead to air emissions. Roofing kettles typically consist of single-shell heating from tubes that contain the burner flame or hot combustion gases. Due to this unsophisticated heating system, temperatures along the single-shell heating system are irregular. For example, the hottest temperatures may occur at the location of the burner flame, the return bends of the tube, and at the bends leading to the exhaust pipes. Temperatures above 1,000°F have been recorded at these locations, which results in thermal destruction or cracking of the asphalt. Thermal cracking in turn leads to the formation of smoke, particulate matter, and volatile hydrocarbon emissions. A relatively minor amount of hydrocarbons are expected to be emitted during the application of hot roofing asphalt.

8.1 Activity Data for Roofing Materials

The total 1986 roofing material consumption in California was 673,000 tons/yr (Bukowski, 1987). This amount includes both roofing asphalt and roofer's pitch. Of the total amount of material consumed, approximately 20 percent is used in built-up roofing and the remainder is used to manufacture tar paper and felts. Approximately 85 to 100 percent of the built-up roofing in California is done using asphalt, and the remaining 15 percent is done using roofer's pitch (Walts, 1987). Based on survey data, the Fresno County APCD estimates that 93 percent of all built-up roofs are manufactured using hot application, and the remaining 7 percent with cold asphalt. A qualitative discussion of the quality of these estimates is presented in Section 8.3.

8.2 Emission Factors for Roofing Materials

The emission factors used for this category were experimentally developed in a program managed by the Fresno County APCD (Fresno County APCD, 1982). In the source tests conducted by the APCD, Type III asphalt was selected and used because it is the most commonly used asphalt in California. The source test was designed to measure emissions from a roofing kettle, subject to the operational demands typically encountered during a roofing job. Each day, the kettle was operated for 8 hours, corresponding to a normal work day. The operator would open the vat cover, charge the kettle with 2 to 4 asphalt plugs, and allow the asphalt to liquify with the lid closed. When the kettle temperature reached the proper level, the asphalt would be pumped to a tanker truck parked adjacent to the kettle. Asphalt was to be charged when the level within the vat reached a predetermined height. The kettle was emptied and recharged 12 to 14 times each day. A ventilation hood placed directly over the kettle captured volatile hydrocarbons escaping from the kettle through leaky seals and from the vat cover.

Two separate runs were made on consecutive days. The average measured emission factors were 0.00001 pounds of TOG per pound of asphalt melted and 0.0002 pounds of particulate matter per pound of asphalt melted. Although it is not documented, the test report lists cold asphalt as having 38 percent volatile constituents by weight. We assume this information was obtained from the trade association (Roofing Contractors Association) who participated in the source testing.

As a final point, the source test was conducted under conditions "encountered during a roofing job." During the source testing, the lid to the kettle was only opened during recharging. However, according to Puzinauskas (1979), "a common practice is to leave the cover open during the working day." If this is indeed true, the emission factors developed by the Fresno County APCD understate the emissions. This possible inaccuracy is accounted for in our uncertainty analysis discussed in Section 8.3.

8.3 Emission Estimates for Roofing Asphalt

Table 8-1 presents the refined emission factors, activity data, and emission estimates for this source category. The confidence intervals for the estimates were calculated using equations 11-3 and 11-4. A discussion of the uncertainties in the activity data and the emission factors follows.

The total amount of roofing materials consumed in California was provided by the Asphalt Institute and is assumed to be fairly accurate. The estimate that 20 percent of the total consumption of roofing materials is used for built-up roofs is assumed to be accurate within 15 percent. The estimate that 93 percent of the roofing materials are applied hot was determined by a survey conducted by the Fresno County APCD and is assumed to be applicable to the rest of the state. The applicability of the activity data is 100 percent.

The emission factors were experimentally developed by the Fresno County APCD. Our confidence in these factors is only 80 percent due to the possible positioning of the kettle lid as discussed in Section 8.2. In this

TABLE 8-1. REFINED EMISSION ESTIMATES FOR ROOFING ASPHALT

Pollutant	Activity Data (ton/yr)	Emission Factor (lb/ton)[a]	Refined Emission Estimate (ton/day)[b]
TOG (cold application)	9,500 (8,000; 11,000)	760 (440; 1,100)	10 (4.9; 16)
TOG (hot application)	126,000 (107,000; 140,000)	0.02 (0.012; 0.03)	<0.01 (<0.1)
Total TOG			10
PM (hot application)	126,000 (107,000; 140,000)	0.34 (0.22; 0.46)	0.06 (0.03; 0.09)

[a] Values in parenthesis represent 95 percent confidence intervals.

[b] Values in parenthesis represent 90 percent confidence intervals.

report, the roofing asphalt emission factors are being applied to activity data comprised of both roofing asphalt and roofer's pitch. Therefore, they are estimated to have an applicability of 80 percent.

A survey conducted by the Fresno County APCD concluded that built-up roofing activities occur, on the average, five days per week, 50 weeks per year. The spatial resolution of the emission estimates can be estimated in several ways. Two methods are discussed below.

First, an estimate may be obtained by determining, county-by-county, the amount of commercial rental space available. Since the majority of built-up roofs are on commercial buildings, the emission estimates can be scaled county-by-county according to the commercial rental space available in each county. The applicability of this method is assumed to be 90 percent.

A second, less time-consuming method, would be to determine the population and amount of commercial rental space available in an urban, a suburban, and a rural county. Using these three data points, a graph of available commercial rental space, as a function of population, can be constructed. With this graph, the amount of rental space in the remaining districts can be determined once their populations are known. As in the previous method, the emission estimates can be disaggregated using available commercial rental space as a template. The applicability of this method is assumed to be 80 percent.

8.4 TOG Speciation Data for Roofing Materials

A speciation profile for a tar kettle is presented in Table 8-2. For comparative purposes, the following data illustrate the differences among several asphalt products (Puzinauskas and Corbett, 1978).

TABLE 8-2. TOG SPECIES PROFILE FOR AN ASPHALT ROOFING TAR KETTLE

Species	Weight Percent
isomers of hexane	3.4
isomers of octane	7.4
C-7 cycloparaffins	2.9
C-8 cycloparaffins	0.4
C-9 cycloparaffins	1.5
isomers of pentane	1.1
propane	10.2
n-butane	11.6
isobutane	0.7
n-pentane	6.3
n-hexane	4.9
n-heptane	2.0
n-octane	2.7
cyclopentane	2.5
isomers of pentene	0.5
ethylene	0.3
propylene	2.0
butene	7.0
i-pentene	3.2
toluene	1.9
methane	21.3
ethane	3.4
benzene	0.8
TOTAL	100.0

Source: U.S. EPA, 1980; Data Level Confidence III - Average Confidence, "Based on data which seem reasonable and should be more or less representative of the population."

Species	Asphalt Cement (AC-10)	Road Tar (RT-12)	Roofing Asphalt (Type III)	Roofers Pitch (Type A)
Aromatic Carbon	34	80	37	79
Naphthene Carbon	23	15	23	18
Paraffin carbon	43	5	40	3

These data suggest that roofing asphalt, the primary roofing material used in California, is very similar in hydrocarbon composition to asphalt cement.

Another important consideration for this emission source category is the emission of air toxics compounds, specifically polynuclear aromatic hydrocarbons (PAH). We identified two data sources that present PAH speciation data. These data are summarized in Tables 8-3 and 8-4. Due to the semivolatile nature of PAH, the data in Tables 8-3 and 8-4 are presented as weight percents of particulate matter emissions.

TABLE 8-3. PARTICULATE MATTER SPECIES PROFILE FOR ROOFING ASPHALT[a]

	Asphalt A[b], 630°F	Asphalt B[c], 590°F
Total Benzene Solubles[d] (mg/m^3)	559	1,074
Polynuclear Aromatics ($mg/m^3 \times 10^{-4}$)		
Pyrene	480	408
Fluoranthene	330	340
Benz(a)anthracene	420	260
Chrysene	890	760
Triphenylene	780	740
Methyl Benz(a)anthracene	780	500
Benzo(a)pyrene	280	100
Benzo(e)pyrene	820	220
Benzo(g,h,i)perylene	80	<60
Methyl Benzo(a)pyrene	180	70
Methyl Benzo(e)pyrene	650	320
Benzo(g,h,i)fluoranthene	170	<200
Benzo(b)fluoranthene	180	<30
Benzo(j)fluoranthene	<10	<60
Benzo(k)fluoranthene	100	<100
Perylene	200	220
Coronene	<10	<10
Phenanthrene	210	220
Total PNAs[e]	6,570	4,618
Total PNAs, percent[f]	0.12	0.04

Source: Puzinauskas, 1979.

[a] The measurements were made using a Filter-Tenax Sampler 15-30cm above the asphalt surface in the tar pot.

[b] Asphalt A is a low-volatility asphalt.

[c] Asphalt B is a high-volatility asphalt.

[d] Benzene-solubles make up 95-99 percent of the total particulate matter.

[e] Values marked as less than (<) included in total PNAs.

[f] Based on benzene-solubles.

TABLE 8-4. PAH SPECIATION DATA FROM FRESNO TAR POT SOURCE TEST DATA

	PAH Concentration (ug/g)[a]			
Tar Kettle Exhausts	Phenanthrene	Chrysene	Benz(a) Anthracene	Benz(a) Pyrene
Test 1	210	64	110	<7
Test 2	95	55	60	<2

Source: Fresno APCD, 1982.

[a] Microgram of PAH per gram of particulate matter collected.

9.0 SANITARY SEWERS

This emission source category represents the volatilization of organic compounds from sanitary sewers--the collection systems that transport waste materials to sewage treatment plants. Emissions from sewage treatment plants, more commonly referred to as Publicly Owned Treatment Works (POTW), are not included in this emission source category.

Numerous investigators and regulatory agencies have examined and estimated noncriteria or hazardous air pollutant emissions from POTW. Emissions from POTW were recently examined in an ARB research project (Chang et al., 1987) and also by EPA in a report prepared for Congress (U.S. EPA, 1986). In both of these reports, emissions from sanitary sewers were discussed. And in both cases, recommendations were made to perform additional research to provide the data and information necessary to estimate emissions from sewer systems. (The ARB has begun such research programs in the Bay Area and in the South Coast Air Basin.)

After contacting numerous researchers and regulatory agency staff, in addition to an extensive literature search, we concur with these recommendations. To our knowledge, there have been two attempts to quantify the emissions from sanitary sewers. In the first attempt, a mass balance approach was used to quantify the mass of pollutants that reach a POTW (Levins et al., 1979). These researchers used information on the amount of waste materials entering the sanitary sewer system and on the amount of waste received at the POTW. The difference between these two mass flows represents the emission rate. Table 9-1 has been prepared based on the information presented in the document. As can be seen from the nonvolatile species, the closure on the calculated mass balances is relatively poor. In fact, two of the mass balances show that there were more volatile compounds received at the POTW than were discharged to the sanitary sewer. These data serve to demonstrate the difficulty in performing mass balances on relatively common volatile species in large sewage systems. A better approach may be to spike a sewer influent stream with a nonroutine, nontoxic volatile compound. Aqueous samples taken downstream would then provide an indication of volatilization.

TABLE 9-1. EVALUATION OF VOLATILE SPECIES IN SEWER LINES USING A MASS BALANCE APPROACH[a]

	Percent Emitted in Sewer Line			
	Cincinnati	St. Louis	Atlanta	Hartford
Volatile Species	73	12	(245)[b]	(30)[b]
Semivolatile species	44	62	45	74
Nonvolatile species	35	21	32	55

[a] Source: Adapted from Levins et al., 1979.

[b] Values are negative, indicating more volatile compounds were received at the POTW than were discharged to the sewer.

In preparing the report to Congress, EPA used an open channel dispersion model to predict emissions from sanitary sewers (O'Farrel, 1987). Results of the modeling were found to be dependent upon the free air space above the liquid interface and also on the amount of fresh air exchanged in the system. The modeling results predicted relatively low emission rates. As the free air space and fresh air exchanges decrease, the air above the liquid stream becomes "saturated" with volatile materials, decreasing the mass transfer driving force. Results of the modeling effort have been termed inconclusive by the EPA.

The results of the modeling attempts prompted a currently ongoing research effort by EPA with the City of Cincinnati. This is a two-year research program involving the spiking of sewer inlets and actually measuring emissions from the sewer lines and connections (Bishop, 1987).

Although little is known about pollutant fate and behavior in sanitary sewers, it is believed that a significant fraction of the the volatile species are emitted during passage through the sewer system. A comparison of air concentrations to wastewater concentrations of volatile compounds measured at sewer mains indicated an average ratio of 9,000 to 1 for air to water concentrations (Dixon, 1984). These particular data support the belief that most volatile species are emitted in the sewer system rather than at the POTW.

10.0 WIND EROSION

Emissions of wind blown dust have been estimated for various parts of California by the ARB, at least one Air Pollution Control District, and the U.S. EPA Region IX. The purpose of this section is to review the methodologies that have been used and provide suggestions for improving the current emission estimates.

This emission source category includes windblown fugitive dust emissions that result from wind erosion of agricultural lands, desert lands, and unpaved roads. An extensive literature review was performed and numerous phone contacts were made for each of these sources in an effort to identify the best available emission factors and emission estimation methodology. This research indicates that the method that ARB is currently using to estimate emissions from agricultural lands, with one major modification, is the best available method given existing data. Windblown dust emissions from desert lands are difficult to estimate with any degree of certainty at this time, due to of the lack of data and emission factors applicable to the wide variety of conditions found in desert lands. With regard to unpaved roads, we concur with other researchers that wind blown emissions from unpaved roads are relatively minor in comparison to vehicle-generated emissions from unpaved roads. In the discussions below, we present several suggestions for field and/or research efforts that might serve to refine emissions estimates.

10.1 Agricultural Lands

10.1.1 Emissions from Agricultural Lands

This source is not currently included in the statewide emission inventory, but ARB has made preliminary emission estimates for this source using a formula developed by the U.S. Department of Agriculture (USDA) for estimating topsoil losses from wind erosion. Based on our literature review, this procedure appears to be the most appropriate method because the same variables which affect the rate of topsoil losses, also affect the generation of suspended particulate. Our research indicated that this equation is universally applied in this country for estimating windblown dust emissions from agricultural lands. The equation is (Cowherd, 1974):

$$E = (FS)\ (I)\ (K)\ (C)\ (L')\ (V') \qquad (10\text{-}1)$$

Where: E = suspended particulate resulting from wind erosion of tilled fields, tons/acre-year.

FS = fraction of wind erosion losses that would be measured as suspended particulate. This is assumed to be 0.025 (2.5 percent) based on research by PEDCo.

I = soil errodibility based on the fraction of soil less than 0.84mm equivalent diameter. Values are taken from soil maps presented in the literature (Cowherd, 1974) and average county values are estimated.

K = surface roughness factor. This is assumed to be a function of the crop being grown and is taken from a table in the literature (Cowherd, 1974).

C = climatic factor, which is a function of wind speed, temperature, and rainfall. Maps containing these values are prepared by the U.S. Department of Agriculture (U.S.D.A., 1986).

L' = unsheltered field width factor, which is a function of unsheltered field width, surface roughness (K) and errodibility (I). Average values of field width and errodibility for different crops are taken from a table and applied to a figure presented in the literature (Cowherd, 1974).

V' = vegetative cover factor, primarily the crop residue left on the ground over the time interval between harvest and new crop growth. Typical lb/acre values are taken from a table and the V' value is estimated from a table in the literature (Cowherd, 1974).

The U.S.D.A.'s references are the result of many years of research and have not been altered since the printing of Cowherd's work (Bunter, 1987).

Radian used this methodology in the Phase I portion of this study and estimated the annual windblown dust emissions from agricultural lands in California (using equation 10-1). The acreage of various crops in each county was obtained from 1983 county crop reports by the ARB. These data were used in conjunction with emission factors estimated using equation 10-1. The climatic (C) factor was taken from USDA 1986 interim maps for each county using the same references as those used by the ARB.

The California statewide particulate matter emissions from agricultural lands were originally estimated by Radian to be 1,500 tons per day. Since that time, the ARB has refined the factors originally used in the estimate, which have increased the estimate to 3,500 tons per day. This increase is due to changes in the erodibility and unsheltered field width factors. As the ARB continues to evaluate this source category, additional refinements are expected. Therefore, the estimate of 3,500 tons per day should be considered preliminary.

10.1.2 Suggested Enhancements to Emission Estimates for Agricultural Lands

At this point, irrigation of crops is not considered in the emission estimate. Approximately 8.5 million acres of California agricultural land is under irrigation, consuming 90% of California's water supply (Ruffner, 1980). Cooper et al. (1979) estimated that emission estimates for windblown dust from agricultural lands in California should be reduced by 71.9 percent to account for irrigation. The preferred method would be to modify the climatic (C) factor of each county for each crop. The climatic (C) factor, as used in equation 10-1, is calculated from the following equation:

$$C = \frac{(0.345)V^3}{\left[115 \sum_{1}^{12} \left(\frac{PM_i}{TM_i - 10}\right)^{10/9}\right]^2} \qquad (10\text{-}2)$$

Where

V = wind speed
PM = monthly precipitation in inches
TM = average monthly temperature in degrees Fahrenheit (set equal to 28.4° if below 28.4°)

In order to adjust each county climatic (C) factor to account for irrigation, data should be gathered on the amount of water required to grow each crop in each soil type and temperature found in the county. The quantity of irrigation water would be added to the rainfall value used to calculate the climatic (C) factor.

If a temporally resolved emission estimate is required, two other factors must be considered, the vegetation factor and the mean energy velocity of the wind. The U.S. Soil Conservation Service often subdivides the year into four to eight periods for their emission estimates. Recognizing that most erosion occurs during the time period between harvest and emergence of the new plants, they assign a vegetative cover factor (V') to each crop for each time interval (Bunter, 1987). ARB should follow the same procedure if this degree of resolution is desired.

The other variable which must be considered in a temporally resolved emission estimate is the wind velocity, which is contained in the climatic (C) factor (see equation 10-2). When calculating a climatic (C) factor for a specific time period of the year, it is important to remember that the numeric mean wind velocity is of no use in an equation which is a function of the cube of the wind velocity. Actually, the parameter of concern is the energy of the wind, rather than the velocity of the wind. The Mean Energy Velocity "V_e" for a time period during which "n" measurements of the wind velocity "V" are taken at equal intervals is given as:

$$V_e = \left(\frac{\sum_{1}^{n} V_i^3}{n} \right)^{1/3} \qquad (10\text{-}3)$$

The following example illustrates the importance of using the mean energy velocity (V_e) of the wind in calculations of the climatic (C) factor. Assume that four measurements of wind velocity are taken in each of two areas, A and B. Assume that these measurements are:

Area A: 10 mph, 10, mph, 10 mph, 10 mph
Area B: 40 mph, 0 mph, 0 mph, 0 mph

Both areas have numeric mean wind velocities of 10 mph. Using equation 10-3, however, produces very distinct velocity cubed ($\bar{V}^3$) values to be used in equation 10-2:

$$\text{Area A} \quad Ve_A{}^3 = \left[\left(\frac{10^3 + 10^3 + 10^3 + 10^3}{4}\right)^{1/3}\right]^3$$

$$Ve_A^3 = 1{,}000$$

$$\text{Area B} \quad Ve_B{}^3 = \left[\left(\frac{40^3 + 0^3 + 0^3 + 0^3}{4}\right)^{1/3}\right]^3$$

$$Ve_B^3 = 16{,}000$$

As can be seen from equations 10-1 and 10-2, the climate (C) factor, and thus the suspended particualte (E) is a linear function of the value of $\bar{V}^3$.

Therefore, while both areas have the same numeric mean wind speed, Area B would actually suffer 16 times as much wind erosion as Area A. For this reason, the U.S. Soil Conservation Service adjusts its short term climatic (C) factors based on the mean energy velocity for the time period under study, relative to the annual mean energy velocity of the wind.

In calculating the windblown dust emissions from the South East Desert Air Basin, the EPA estimated the emissions resulting from each measured wind speed separately (Ono, 1987). This method is mathematically analogous to using the mean energy velocity. The ARB should use the mean energy velocity weighting technique just as the Soil Conservation Service does if temporally resolved estimates are required.

Further, the reader should be cautioned that the wind energy velocity may not be relevant to all windblown dust emissions. Research on dry lake beds and industrial sites has indicated that emissions from these sources is sensitive only to how often the wind exceeds a fixed threshold velocity and not to the actual wind speed (Bohn, 1978; Cahill, 1987).

10.1.3 Confidence Interval of Agricultural Lands Emission Estimates

Activity data, or the amount of agricultural lands, appears to be of high quality and extremely detailed. The emission factors generated from the modified USDA equation, however, are questionable. When emission factors result from multiplying a set of variables together, propagation of errors can be used to estimate the uncertainty of the estimates. This concept is discussed in greater detail in Section 11.0.

Determination of a rigorous 95 percent confidence interval would require a statistically valid set of data, defining the extent and distribution of possible values for each term in the modified USDA equation. Extensive review of U.S. Soil Conservation Service calculations might provide this data for the I, K, C, L', and V' terms. No data exists, however, to define these parameters for the FS term for California. As will be shown, this is the term which drives the uncertainty estimate for the emission factor. Sources of uncertainty, along with a subjective estimate of their range for each variable are discussed below.

- Fraction of the soil that can be suspended (FS). Different sources assume maximum suspendable particle sizes ranging from 30 to 50 microns. The suspendable fraction normally used with this equation is 0.025 (2.5 percent). It should be noted that the USDA researchers who developed the wind erosion equation are not in agreement with using the equation for estimating emissions. They cite data which indicate that from 3 to 40 percent of soil movement over test fields is in suspension rather than moving by surface creep or saltation. Some of the material collected in these tests was larger than 84 microns and would therefore remain entrained only for a relatively short time. However, the range of values measured indicates that the use of a single, universal constant may result in significant errors in individual estimations. As a subjective estimate for the purposes of estimating uncertainty, the value of this term was assumed to deviate by 0.015.

- <u>Soil Errodibility (I)</u>. This factor describes the soil that is less than 0.83mm in size. This factor is a function of soil type with values ranging from 38 to 220 tons per acre per year (Cowherd, 1974). Uncertainty would result from widely varying soils in the sample area. California soils are relatively consistent ranging from silty clay loam (I=38) to loam (I=56) in cultivated areas. This value can be determined independently or taken from maps (Cowherd, 1974). Values for this term were assumed to deviate by 20 percent of the estimated value.

- <u>Surface roughness resulting from irrigation ridges, furrows, and large clods (K)</u>. K can be calculated or taken from a table of average K values for different crops (Cowherd, 1974). This value ranges from 0.5 to 1.0 and is not expected to error by more than 10%.

- <u>Climatic factor (C)</u>. This value is calculated from equation 10-2.

The climatic factor, more than the other factors in this equation, quickly becomes less exact as an averaged value is applied to smaller areas and shorter time spans. It is also important to note that, given equivalent values for the other parameters, a 100 mph Santa Ana wind entrains 125 times as much particulate in an hour as a 20 mph wind. A year with severe wind storms can therefore have windblown dust emissions four or five times those of a year with no such storms. In addition, neglecting the effects of irrigation in arid regions results in a C factor as much as an order of magnitude high for some crop types. Values for C range from 0.01 to 5.0 across California agricultural lands. For annual averages on a county wide basis, deviation in this term was expected to be 50 percent of the value used. This estimate neglects the irrigation question and assumes no extraordinary storm activity.

- Unsheltered Field Width Factor (L'). For a given crop type, this factor is affected by field size and the presence of wind breaks in the area. Across California crop lands, the value of this term ranges from 0.2 to 0.7. Taken as a county average for each crop, this term was assumed to deviate by 0.05.

- Vegetative Cover Factor (V'). This term is a strong function of season and crop type. Values for this term range from 0.05 for alfalfa to 0.97 for broccoli in California. Deviation from annual average values assigned to specific crops was assumed to be 0.01.

As discussed in Section 11.0, equation 11-7 can be used to estimate the standard deviation that results from multiplying several independent variables together.

Equation 11-7 is normally used with the standard deviations or confidence intervals of the terms in an expression to generate the standard deviation or the confidence interval for the whole expression. In this case it was not possible to calculate standard deviations for the values of the terms in the expression, so deviations from the estimated values were arrived at subjectively. This method was used to generate a 95 percent confidence interval for the 1983 windblown dust emission estimate for cotton crop land in Riverside County (see Section 11.0).

Using the deviations in the individual terms that were estimated above, and assuming that two deviations to either side of the estimated value are necessary to define a 95 percent confidence interval, emissions from this source could range from zero to 29,300 tons/year. Further, the magnitude of the deviation is almost entirely dependent on the deviation estimated for the FS term. If the deviation in this term is determined to be higher or lower than estimated, the deviation of the emission estimate will follow, down to the plus or minus 10 percent range, where the deviations in the other terms become significant.

10.2 Desert Lands

10.2.1 Emissions from Desert Lands

California has 15.3 million acres of desert lands, roughly 15 percent of the State's area (Fay, 1986). Of these desert lands, 12.5 million acres are public land, while the rest are controlled by the military or private entities.

The EPA (Region IX) estimated PM emissions from the South East Desert Air Basin (SEDAB) of California at 7,900 tons per day (Ono and Bird, 1987). This estimate was calculated using the following equation:

$$F = 1.78\text{x}10^{-16}\ U^{2.782} \qquad (10\text{-}4)$$

Where

F = aerosol flux, g/cm^2-s (total suspended particulates)

U = wind speed at 10 meters in cm/sec

Source: (Nickling and Gillies, 1986).

The following assumptions were made in this estimation:

- Undisturbed desert is 'crusted' and has negligible windblown dust emissions. This is true for some areas of California desert (Chambers, 1987).

- The portion of the SEDAB that is 'disturbed' is 25 percent of the total area minus the area occupied by population centers. This area totaled 525,500 acres. (This assumption was arbitrary - no data was available upon which an estimate could be based.)

- The lower wind speed threshold resulting in particulate entrainment is 18.1 mph.

Extrapolating this estimate to include the desert area in the Great Basin Valley air basin might increase the PM estimate by 25 percent, to 10,000 tons per day. We feel, however, that this would still be an underestimate of emissions from windblown dust in California deserts. Reasons for this are described below.

While 'crusted' undisturbed desert areas may not emit significant emissions, observations indicate at least two significant sources of windblown dust that exist in undisturbed desert areas:

- Flood plains; and
- Owens and Mono Lakes.

Overflowing rivers deposit several centimeters of fine silt on the flood planes. When the silt has dried, high winds sweep the flood planes clean, picking up dense clouds of suspended particulate matter. It is typical for the road between Palm Springs and Desert Hot Springs to be closed one or two days per year because of poor visibility which is caused by windblown dust (Bunter, 1987). If the size of the flood plane and the depth of the silt were measured, this emission would be quantifiable.

The diversion of Owens Valley water to Los Angeles has resulted in the desiccation of Owens lake. Silt picked up from the lake bed creates severe visibility problems for military activities at China Lake Naval Weapons Center and Edwards Air Force Base (Chambers, 1987). Air quality sampling sites downwind of Owens and Mono Lakes approximate or exceed the federal emergency level of 1000 mg/m^3 on 5 percent of all days (Kusco, 1984). Dr. Thomas Cahill of U.C. Davis has designed, for ARB, a model for emissions from Owens Lake. This semi-empirical model, MODEM, calculates air concentrations of particulates resulting from specific wind storms. The model is highly sensitive to the recent climatological history of the lake bed area and is not sensitive to actual wind velocity. Dr Cahill has modified this model for use in the Mono Lake area (Cahill, 1987).

10.2.2 Suggested Enhancements to Emission Estimates for Desert Areas

One source of information has been identified that, in conjunction with considerable research and data gathering, may be of use in estimating emissions from desert areas. The entire state of California has been photographed from 58,000 feet. These photographs are available from the United States Geological Survey. Each photograph depicts 900 square miles of area. Available formats include:

- Color;
- Black and white;
- Color infra-red; and
- Black and white ortho-photo (corrected for earth's curvature).

Landsat photographs have been used to locate and identify foliage for use in vegetative TOG emission calculations in the Bay Area. It is unknown, however, if the infra-red signature of crusted desert is sufficiently distinct from that of disturbed desert or rocky desert to make surface identification possible. It must be emphasized that these photographs have never been used for this purpose.

Visible light photographs might be used to locate and quantify the areas of alkali lake beds and flood planes. In order to use either type of photograph, extensive field observations of soil surfaces would need to be made and it would be important to consider the year and season that the photograph was taken when using field observations to interpret photographic data.

Dr. Cahill's model of windblown dust emissions from Owens and Mono lakes could be useful in future work in estimating emissions from these sources. The calculations, however, would not be straightforward and would require that detailed meteorological records be gathered for the lake bed areas. Conversion factors would need to be calculated to convert PM concentrations to ton per day emission values. This approach would require a high level of effort. It would, however, provide a spatially and temporally resolved estimate of the emissions from these sources.

10.2.3 Confidence Interval of Desert Land Emission Estimates

The activity data (acreage) for disturbed desert lands has thus far not been defined and quantified. The emission estimation equation used has not to our knowledge been independently evaluated or verified by measurements. Several significant types of California desert windblown dust emissions are not addressed by this equation. For these reasons, the 10,000 ton/day figure mentioned above for windblown dust emissions from desert lands should not be considered accurate to better than an order of magnitude in either direction.

10.3 Unpaved Roads

10.3.1 Emissions from Unpaved Roads

Literature on the methodology used for several emission inventories throughout the United States was reviewed. In all but one case, the windblown dust from unpaved roads was neglected. It has been assumed that the suspendable fraction of the road surface is effectively swept away by passing vehicles, leaving little to be removed by the wind. Typically the suspendable fraction assumed for traffic-based emissions is the value of the surrounding soil. Many field tests have shown that road silt content is normally lower than the surrounding parent soil because of the phenomena described above (Cowherd, 1974). Wind blown emissions are therefore assumed to be small relative to the conservative margin and the uncertainty of the traffic-based estimates. While these assumptions seem reasonable, no empirical data that we are aware of supports them.

For the purposes of estimating the magnitude of windblown emissions from unpaved roads in California, the modified USDA equation (discussed in Section 10.1) was applied to the area of unpaved roads in California. Unpaved road mileage for each county in 1983 was obtained from CALTRANS via the ARB.

The roads were assumed to be 25 feet wide and the emission factor for each county was generated by assuming a smooth surface with no vegetative cover and with no sheltering trees or structures near the edge of the road in the modified USDA equation. We have estimated the statewide TSP emissions from wind erosion of unpaved roads at 92 tons per day using the following factors in the modified USDA equation:

- FS = 0.038 (U.S. EPA, 1977);
- I = average value for each county (see Appendix B for individual values);
- C = average value for each county (see Appendix B for individual values);
- K = 1.0;
- L' = 0.3 based on a value of I ranging between 40 and 50 (U.S. EPA, 1977); and
- V' = 1.0.

The Guideline for Development of Control Strategies in Areas with Fugitive Dust Problems (U.S. EPA, 1977) lists the FS term applicable to this situation as 0.38 and 0.038 in different portions of the document. We contacted the U.S. EPA and confirmed that 0.038 is the correct value. (A value of 0.38 indicates that 38 percent of the wind erosion losses would be measured as suspended particulate--a gross error). Detailed results of our emission estimate are presented in Appendix B.

The ARB 1983 Emissions Inventory lists total statewide entrained road dust PM from vehicular traffic on unpaved roads as 540 tons per day (ARB, 1986). The estimated 92 tons per day of windblown dust may be within the uncertainty of the entrained road dust emission estimate.

10.3.2 Suggested Enhancements to Emissions Estimates for Unpaved Roads

Because the estimate for emissions from this source is so small relative to total unpaved road emissions, we recommend that any further work in this area be directed toward refining the emission estimates for vehicle-caused emissions from unpaved roads. These efforts should include area and road type specific documentation of surface silt content for unpaved roads in California.

10.3.3 Confidence Interval of Emissions Estimates

Because the methodology used to make this estimate was equivalent to that used to estimate windblown dust emissions from agricultural lands, the discussion of uncertainty presented in Section 10.1.3 applies here as well. For a 92 ton per day estimate, the confidence interval would therefore range from 0 to 230 tons per day.

11.0 STATISTICAL PROCEDURES USED TO ESTIMATE CONFIDENCE INTERVALS

Establishing confidence intervals was an integral portion of developing the methodologies for refining the eight source categories selected for the second phase of this study. This section provides a description of the procedures used to establish confidence intervals. Example calculations are also presented.

In developing a confidence interval for an emission estimate, confidence intervals must first be developed for both the activity data and the emission factor. The calculation of these confidence intervals depends on the type and extent of data and the information available. For example, one (or more) of the following types of data, listed in order of decreasing complexity, will normally be available for an emission factor:

- Data and information used to develop an emission factor from one sampling or surveying episode;
- Several different independent emission factors developed for the same source category;
- One of the above for a similar, but not identical, source type; or
- Data from several tests of each of several sources.

The methodologies developed and applied in this study are applicable to the first three cases listed above. We did not encounter any data that required evaluating data from several different emission factors developed for the same source category.

Section 11.1 presents the conceptual approach used to establish confidence intervals for the emission factors, activity data, and subsequently, the emission estimates. Section 11.2 discusses the detailed statistical methods used to estimate 90 percent confidence intervals. (The specific methodology used to determine confidence intervals for each source category is discussed in Sections 3 through 10.)

11.1 Conceptual Approach to Estimating Confidence Intervals

There are two important aspects in providing information on confidence intervals for emission estimates: qualitative and quantitative. Wherever possible, we translated qualitative information on uncertainties to quantitative estimates of confidence limits. This was done even in cases where estimating these confidence limits was very subjective.

This type of procedure is often necessary when the emissions to be estimated may not be from sources strictly comparable to the sources from which the data were obtained, or the measurement methods may not be strictly comparable. If either or both are sufficiently different, the estimated mean value or range of estimated mean values for the emissions were adjusted by an "applicability factor" to attempt to account for the lack of comparability. The applicability factor is expressed as a percentage of the estimated value or of the mid-point of the range of estimated values. Enlargement of an estimated value, or range of estimated values by an applicability factor is an attempt to express more accurately the size of the uncertainty of the stated level of confidence.

The methods used to determine confidence intervals required specific information on activity data and emission factor uncertainties. For each source category, we addressed the following questions in order to establish confidence intervals.

Activity Data Uncertainty

1. What is the source of the activity data?
2. How were the activity data derived (e.g., measurement, compilation of data, survey, engineering estimate, etc.)?

3. If the activity data are a compilation of individual data points, what is the source of these data points?

4. If the activity data are based on a survey, what percentage response was obtained?

5. What is the best estimate of a 95 percent confidence interval for the activity data?

Applicability of Activity Data

1. What differences exist between the sources for which emissions are being calculated and the sources for which the activity data were developed?

2. What is the best estimate of the percent error that is introduced by nonapplicability of activity data?

Emission Factor Uncertainty

1. Is there any ranking of uncertainty that is available for the emission factor and the scale that is applicable to this ranking?

2. If the emission factor is based on test data, how many tests were performed?

3. What are the similarities or differences between the emission sources that the emission factor was based on?

4. What is the best estimate of a 95 percent confidence interval for the emission factor?

5. If the actual test data are available, calculate the range of emission factors that represent a 95 percent confidence interval.

Applicability of Emission Factors

1. What differences exist between the sources for which emissions are being calculated and the sources for which the emission factors were developed?

2. What is the best estimate of the percent error that is introduced by non-applicability of the emission factor?

Once this information was determined, the uncertainty and error estimates were conceptually combined as follows:

$$\left.\begin{array}{l}\left.\begin{array}{l}\text{Activity Data Range}\\ \text{Activity Data Applicability}\end{array}\right\}\begin{array}{l}\text{Activity data confidence}\\ \text{interval}\end{array}\\[1em] \left.\begin{array}{l}\text{Emission Factor Range}\\ \text{Emission Factor Applicability}\end{array}\right\}\begin{array}{l}\text{Emission factor confidence}\\ \text{interval}\end{array}\end{array}\right\}\begin{array}{l}\text{Emission}\\ \text{estimate}\\ \text{confidence}\\ \text{interval}\end{array}$$

The confidence interval for the emission factors can then be calculated as follows:

$$LCI_{ef} = LEF - A \frac{(LEF + UEF)}{2} \qquad (11\text{-}1)$$

$$UCI_{ef} = UEF + A \frac{(LEF + UEF)}{2} \qquad (11\text{-}2)$$

Where, LCI_{ef} = Lower limit of confidence for the emission factor

UCI_{ef} = Upper limit of confidence for the emission factor

LEF = Lower range of emission factor

UEF = Upper range of emission factor

A = 1 - emission factor applicability

The lower (LCI_{ad}) and upper (UCI_{ad}) limits of confidence for the activity data were calculated in a similar manner.

Once the confidence intervals were estimated for the emission factors and activity data, confidence intervals for the emission estimates were calculated in the following manner:

$$LCI_{ee} = (LCI_{ad})(LCI_{ef}) \qquad (11\text{-}3)$$

$$UCI_{ee} = (UCI_{ad})(UCI_{ef}) \qquad (11\text{-}4)$$

Where, LCI_{ee} = Lower limit of confidence for emission estimate

UCI_{ee} = Upper limit of confidence for emission estimate

Figure 11-1 presents an example calculation for a hypothetical situation.

Activity and Emission Factor Data

1. Range of activity data = 45 to 50 (with a confidence of 95 percent).

2. Applicability of activity data is believed to be 99% for the source type in question.

3. Range of emission factors = 5 to 10 (with a confidence of 95%).

4. Applicability of emission factor is believed to be 90 percent for the source type in question.

Confidence Intervals for Activity Data

$$LCI_{ad} = 45 - 0.01 \frac{(45 + 50)}{2}$$
$$= 45$$

$$UCI_{ad} = 50 + 0.01 \frac{(45 + 50)}{2}$$
$$= 50$$

Confidence Intervals for Emission Factor

$$LCI_{ef} = 5 - 0.1 \frac{(5 + 10)}{2}$$
$$= 4$$

$$UCI_{ef} = 10 + 0.1 \frac{(5 + 10)}{2}$$
$$= 11$$

Confidence Intervals for Emission Estimate

$$LCI_{ee} = (45)(4)$$
$$= 180$$
$$UCI_{ee} = (50(11)$$
$$= 550$$

Note: All values have been rounded to two significant figures.

Figure 11-1. Example for Conceptual Approach to Estimating Confidence Intervals.

Ninety-five percent confidence intervals were established for the emission factors and activity data. However, when the emission factor and activity data confidence intervals are combined, the resulting confidence in the emission estimate interval is no longer 95 percent. For practical purposes, the lower bound confidence level of the product is the product of the respective levels of the factors (i.e., the level of the "product" of two 95 percent confidence intervals is: (0.95)(0.95) = 0.9025). This assumes that the two variables are statistically independent. Therefore, the emission estimate intervals developed in this document using this methodology are expressed as 90 percent confidence intervals. (Wind blown dust is the only emission category where this method was not used.)

11.2 Statistical Methods Used to Estimate Confidence Intervals

For all confidence intervals, we assumed the activity and emission factor data were normally distributed. (Quite often environmental data are analyzed assuming they follow a log normal distribution.) We tested this assumption using the data gathered for developing the TOG emission factor for beef cattle. Test statistics showed that either a log normal or normal distribution were appropriate for evaluating this specific data set. Therefore, since it was not conclusive from the sample data what distribution the beef cattle data follows, the normal distribution was used to evaluate all data.

Typically, emission estimates are calculated by multiplying an emission factor by a measure of activity (e.g., process throughput, surface area, fuel consumption, etc.) that describes the source category. Emission factors are developed from sets of data measurements or developed from mathematical expressions that attempt to model the source category. Examples of these two situations include emission factors for fireplaces and mathematical expressions used to estimate windblown dust emissions. Fireplace emission factors are generated through source testing, where numerous data points are generated and averaged together. In the case of windblown dust, a site specific emission factor is calculated by multiplying together six independent variables that describe the physical characteristics of that particular site. Section 11.2.1 describes the mathematical procedures used in this study to calculate confidence intervals from emission factors developed from data measurements. Section 11.2.2 presents similar information for emission factors developed from a mathematical equation.

11.2.1 Developing Confidence Intervals from Data Sets

If a data set is normally distributed, the following standard equation can be used to estimate a confidence interval for the data set:

$$CI = (\bar{x} - ts/\sqrt{n}\ ,\ \bar{x} + ts/\sqrt{n}\ ) \qquad (11\text{-}5)$$

where: $\bar{x}$ = the sample mean,
t = the value of the standard normal deviate corresponding to the desired confidence level,
s = the standard deviation, and
n = the sample size.

This approach is best used to calculate the confidence interval for a mean emission factor developed from one set of source test results. This method can also be used to calculate the confidence interval associated with a mean emission factor that has been developed from several independent emission factors when the individual data points making up each emission factor are not available. Although in this latter case this method may not be statistically rigorous, this method provides an estimate of the confidence interval associated with using the mean emission factor.

If more than one data set exists, additional statistical procedures are necessary to calculate an overall mean and standard deviation for use in equation 8-5. This situation frequently arises for emission factors, where independent source test data have been published for a single emission source category. An analysis of variance (ANOVA) may be used to determine if any data (or sets) is different from the others. We did not encounter this type of data in this study and therefore did not use this method.

11.2.2 Developing Confidence Intervals from Emission Factor Equations

In many instances, site specific factors preclude the development of generalized emission factors. A good example, and one of the source categories considered in this project, is windblown dust. Windblown dust emissions from agricultural lands are calculated from the following equation:

$$E = (FS)(I)(K)(C)(L')(V') \qquad (10\text{-}1)$$

Where: E = suspended particulate resulting from wind erosion of tilled fields, tons/acre-year.

In this equation, the emission estimate is a function of each of the six independent variables. As such, the overall variance can be expressed as the sum of the variances of each variable with respect to the emission estimate. Mathematically, the variance of a variable, with respect to the emission estimate, is expressed as the product of the square of the partial derivative of the emission estimate, with respect to that variable, times the variance of that variable. Take for example the simple equation $Q = (a)(b)(c)$. The error S_Q resulting from a, b, and c can be approximated by:

$$S_Q^{\,2} = \left(\frac{\partial Q}{\partial a} S_a\right)^2 + \left(\frac{\partial Q}{\partial b} S_b\right)^2 + \left(\frac{\partial Q}{\partial c} S_c\right)^2 + \cdots \qquad (11\text{-}6)$$

When a,b, and c have an exponent of one, this equation reduces to:

$$S_Q^{\,2} = (bcS_a)^2 + (acS_b)^2 + (abS_c)^2 + \ldots \qquad (11\text{-}7)$$

In this equation, S_Q^2 is the variance of the product and S_Q is the standard deviation of the product. Similarly, S_a, S_b, and S_c are the standard deviations of a, b, and C, respectively. This method is often referred to as propagation of errors (see e.g. Kline and McClintock, 1953 and Moffat, 1982).

The method of propogation of errors was developed to describe uncertainties in single-sample experiments. However, in the most ideal case, numerous measurements of a, b, and c would exist so that rigorous standard deviations can be calculated. These standard deviations then become the S_a, S_b, S_c terms of equation 11-7.

Unfortunately, and as is the case with agricultural land windblown dust emissions, insufficient data are available to calculate the standard deviation of each independent variable. In lieu of this data, subjective judgements can be made about the accuracy of each term. These estimated percent deviations can then be used in equation 8-9 to estimate an overall deviation. At this point, another subjective decision must be made to estimate a 95 percent confidence interval. The 95-percent confidence interval can be approximated by assuming the interval is equal to $\pm$ 2 deviations from the calculated emission rate (see e.g. Peters and Timmerhaus). In the case of windblown dust for agricultural lands, we assumed that the 95 percent confidence interval is $\pm$ 2 deviations from the calculated emission rate. An example for cotton crop land in Riverside County presented in Figure 11-2 illustrates this methodology. For this particular example, the emission estimate is 0.66 tons of particulate matter per year with a 95 percent confidence interval of 2 times the variance (0.48) or $\pm$ 0.96 tons.

A more detailed, but a highly involved method, would be to use a Monte Carlo simulation. Using agricultural windblown dust again as an example, numerous emission estimates would be calculated by randomly choosing a value for each independent variable in the equation that is within the estimated accuracy of that term. The emission estimates (between 1,000 and 10,000 values) would then be ordered from high to low. For 95 percent confidence intervals, the interval would equal the range that encompasses 95 percent of the values. That is, the lowest and highest 2.5 percent of the values would be excluded.

1. Emission Equation:

$$E = (FS)(I)(C)(K)(L')(V')$$

2. Known Values:

$$FS = 0.025$$
$$I = 47$$
$$C = 2.47$$
$$K = 0.5$$
$$L' = 0.52$$
$$V' = 0.88$$

Therefore, E = 0.66 tons of PM/acre · yr

3. Assumed Values:

$$S_{FS} = 0.015$$
$$S_I = 9.4$$
$$S_C = 0.741$$
$$S_K = 0.05$$
$$S_{L'} = 0.05$$
$$S_{V'} = 0.01$$

4. Overall Deviation:

$$S_E^2 = (S_{FS}\ ICKL'V')^2 + (FS\ S_I CKL'V')^2 + (FSIS_C KL'V')^2 + \ldots$$

$$S_E2 = 0.23$$

$$S_E = 0.48$$

Figure 11-2. Example Calculation Using Propagation of Errors

11.3 Conclusions

This section presented the methodologies used to derive confidence intervals for the source categories examined in Phase II of the study. The confidence interval results are given in Sections 3 through 10 together with the refined methodologies developed for these source categories.

12.0 RECOMMENDATIONS

During the development of the preliminary emission estimates and methodologies for refining certain emission estimates, we identified several instances where additional research is needed to provide accurate emission estimates. Our recommendations are given below.

1. Engine population data developed in 1979 have been recommended as the primary data source to determine emissions for exempt stationary and standby engines. This data should suffice for calculating emission estimates for the mid 1980 time period. However, the ARB should consider developing current information that can be used for the late 1980s and early 1990s. This effort would be comparable to the data gathering exercises that were used for the utility lawn and garden emission source category that is currently contained in the 1983 state area source inventory.

2. There are insufficient data at this time to calculate emissions from sanitary sewers that transport waste materials to sewage treatment plants. The ARB is currently considering a research project to generate data that characterize emissions from sewers. This research effort should focus on total organic emissions in addition to air toxics.

3. There is currently insufficient information available to calculate accurate emission estimates for wind blown dust from desert lands. One possible approach to resolve this data inadequacy is to subdivide deserts into undisturbed lands, disturbed lands, and dry lake beds. ARB should then evaluate the possibility of using satellite photos to identify disturbed desert land, the primary source of windblown dust emissions. In addition, a methodology should be developed in conjunction with field data to estimate dust emissions from desert flood plains and dry lake beds.

4. Due to the timing of this project, refined emission estimates were not generated for liquid waste disposal ponds. It appears the necessary information to calculate refined emission estimates will be available from the

State Water Resources Control Board for the 562 liquid waste disposal ponds in California. This information, along with a mass transfer model, could be used to estimate emissions from this source category.

5. The preliminary TOG emission estimates from man-made seeps are 14 to 36 tons per day. In comparison to the other uninventoried sources, this source category appears to be relatively significant. Therefore, we recommend that the ARB give further consideration to refining this emission estimate for inclusion in the statewide emission inventory.

6. Emission inventory data are frequently used in ambient air quality modeling. Accurate speciation of TOG emission estimates is an essential element of ozone modeling. In our data and literature review, we found that the available TOG speciation data are woefully inadequate. The ARB should continue its efforts to develop accurate and current speciation data.

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RADIAN CORPORATION

APPENDIX A

DEVELOPMENT OF AMMONIA EMISSION FACTORS

A.0 DEVELOPMENT OF AMMONIA EMISSION FACTORS

This appendix presents the raw data that were used to develop the ammonia emission factors. More details regarding the assumptions of nitrogen conversion to ammonia can be found in the text.

A.1 Dairy Cattle

Data from Overcash (1983) have been chosen to develop the ammonia emission factor for dairy cattle. The following data points, expressed as lb N/1,000 lb live weight/day for dairy cattle, are available from this reference:

0.40	0.43
0.55	0.63
0.69	0.49
0.37	0.41
0.58	0.54

Conversion factor = 140,000 lb live weight/100 dairy cattle

Summary statistics:

- n = 10
- $\bar{x}$ = 0.51 lb NH_3-N/1,000 lb live weight/day
- s = 0.11
- 95 % CI = +/- 0.079

Based on literature information (see Section 7.0), we will assume that 50 percent of the nitrogen in the manure volatilizes as ammonia. Further, it is assumed that the data presented above are 100 percent applicable to dairy cattle. This yields an emission factor with a 95 percent confidence interval of 130 (+/- 20) lb NH_3-N/year/head.

A.2 Beef Cattle

Date from Overcash (1983) have been chosen to develop the ammonia emission factor for beef cattle. The following data points, expressed as lb N/1,000 lb live weight/day for beef cattle, are available from this reference:

0.34	0.34
0.54	0.42
0.29	0.47
0.30	

Conversion factor = 140,000 lb live weight/100 dairy cattle

Summary statistics:

- N = 7
- $\bar{x}$ = 0.39 lb N/1,000 lb live weight/day
- s = 0.0938
- 95% CI = +/- 0.087

Based on literature information (see Section 7.0), we will assume that 50 percent of the nitrogen in manure volatilizes as ammonia. Further, it is assumed that the data presented above are 100 percent applicable to beef cattle. This yields an emission factor with a 95 percent confidence of 100 (+/- 25) lb NH_3-N/year/head).

A.3 Chickens

Overcash (1983) provides the following data summary for nitrogen content of chicken manure (lb N/day/1,000 lb live weight):

- $n = 32$
- $\bar{x} = 1.20$ N/day/500 chickens
- $s = 0.34$
- 95% CI = +/- 0.15

Overcash also gives the following conversion factors:

- Hen weight = 4 lb; and
- Broiler weight = 2 lb.

Information from various literature sources suggests that approximately 90 percent of the total nitrogen in chicken manure volatilizes as ammonia (see Section 7.0). Further, it is assumed that the data presented above are 100 percent applicable to this source category. From this information and assumptions, the following mean emission factors and 95 percent confidence intervals can be calculated (lb NH_3-N/bird/year):

- Hens = 1.6 (+/- 0.2); and
- Broilers = 0.79 (+/- 0.11).

A.4 Turkeys

Overcash (1983) presents total nitrogen data as a percent of the manure excreted from turkeys. These data, expressed on a percentage basis of wet weight manure are presented below:

1.4	1.6
1.4	1.2
1.2	1.3
1.2	1.6
1.2	

Summary statistics:

- $n = 9$
- $\bar{x} = 1.3\%$
- $s = 0.2$
- 98% CI = +/- 0.19

Overcash also presents the following manure production data (lb/day/1,000 lb live weight):

60	49
72	46
49	

Assuming the average turkey weighs 8 pounds, the following summary statistics can be calculated:

- $n = 5$
- $x = 55$ lb manure/day/125 turkeys
- $s = 10.8$
- 98% CI = +/- 13.6

Applying the mean percent of total nitrogen to the mean manure production rate yields a mean total nitrogen excretion rate of 2.1 lb/year/bird. Applying the concepts expressed in equations 11-3 and 11-4 to the confidence intervals stated above yields a 96 percent confidence interval of 1.3 to 3.0 lb N/year/bird (0.98 x 0.98 = 0.96). For reporting consistency, we have stated this confidence interval as 95 percent rather than 96 percent in the main text of this document.

To determine the ammonia emission factor, we assumed that 90 percent of the nitrogen, as determined for chickens, can be easily converted to ammonia. Further, we assumed that data presented here are 100 percent applicable to turkeys. This yields an emission factor of 1.9 (+/- 0.7) lb NH_3-N/bird/year.

A.5 Hogs/Pigs/Swine

The average total nitrogen content of pig manure was obtained from various literature sources. These data are presented below.

Average Total Nitrogen Content (lb/n/day/pig)	Reference
0.0356	Meek, 1975
0.0396	Overcash, 1983
0.015	Data reported by Cass, 1982
0.017	Data reported by Cass, 1982
0.0105	Data reported by Cass, 1982

Individual data points are not available for these data. Therefore, treating each average a single data point yields the following summary statistics:

- n = 5
- $\bar{x}$ = 0.0235 lb N/day/pig
- s = 0.0131
- 95% CI = +/- 0.016

From Overcash (1983), it appears that 50 percent of the total nitrogen is excreted as ammonia. Therefore, we will assume that 50 percent of total nitrogen excrement volatilizes and is emitted as ammonia. This yields an emission factor of 43 (+/- 3) lb NH_3-N/year/pig.

A.6 Horses

Overcash (1983) presents the following total nitrogen data for horse (lb N/day/horse):

0.35	0.49
0.26	0.35

Summary statistics:

- $n = 4$
- $\bar{x} = 0.36$ lb N/day/horse
- $s = 0.095$
- 95% CI = +/- 0.15

Overcash also states that 40 percent of the nitrogen excreted by a horse is present in the urine. Other literature sources indicate nitrogen present in the urine is readily converted to ammonia. Therefore, we will assume that 40 percent of the nitrogen excreted from a horse volatilizes and is emitted as ammonia. This yields an ammonia emission factor of 52 (+/- 24) lb NH_3-N/year/horse.

A.7 Sheep

Overcash (1983) presents the following data for total nitrogen excreted from sheep (lb N/1,000 lb live weight):

0.53	0.45	0.13
0.32	0.51	0.45
0.43	0.56	0.43
0.20	0.34	0.55
0.45	0.86	0.38

Conversion factor = 125 lb/live weight

Summary statistics:

- $n = 15$
- $\bar{x} = 0.44$ lb N/day/8 sheep
- $s = 0.163$
- 95% CI = +/- 0.09

Assuming 50 percent of the total nitrogen excreted volatilizes and is emitted as ammonia yields an emission factor of 10 (+/- 2) lb NH_3-N/year/sheep. See text for more details.

A.8 Domestic Dogs and Cats

Total nitrogen data for mink were used to approximate the ammonia emissions for dogs an cats. A summary of the mean values for total nitrogen content of mink wastes is presented below.

Average Value (lb/cat/day)	Source
0.01	Martin, 1977
0.011	Martin, 1977
0.01	Overcash, 1983
0.0041	Overcash, 1983

By treating these averages as individual data points, the following summary statistics can be calculated:

- $n = 4$
- $\bar{x} = 0.009$ lb N/day/mink
- $s = 0.0039$
- 95% CI = +/- 0.0061

Based on the percentage of ammonia that volatilizes from other animal manures, we will assume that 50 percent of the total nitrogen excreted by mink is emitted as ammonia. With regard to applicability, we assumed that the data presented here are 80 percent applicable to domestic cats and 50 percent applicable to domestic dogs. This yields the following emission factors (lb NH_3-N/year/animal):

- Domestic cats = 5.7 (+/- 7.3)
- Domestic dogs = 8.6 (+/- 15.4)

A.9 Mountain Lion

Because of the carnivorous diet of lions, total nitrogen data from mink wastes were used to develop the ammonia emission factor for native lion. Overcash (1983) presents data that shows that a mink excretes approximately 0.335 pounds of waste per day per cat. A lion excretes approximately 1.4 pounds per day per animal of total waste. The ratio of these two values was used to adjust the mink ammonia emission factor (see Section A.8) up to account for the difference in animal size.

Due to the lack of any other data, we have assumed that 50 percent of the total nitrogen excreted will eventually be emitted as ammonia. Further, we assumed that the mink data have an applicability of 50 percent for mountain lion. These assumptions yield an emission factor of 6.9 (+/- 5.1) lb NH_3-H/year/animal.

APPENDIX B

WIND BLOWN PARTICULATE MATTER EMISSION ESTIMATES FOR UNPAVED ROADS

Wind Erosion from Unpaved Raods in California.

EF = FS*I*C*K*L'*V' in ton/acre/year

Where: FS = 0.038 (ref 1)

I = average value for county

C = average value for county

K = 1.0

L' = .3 (ref 1, based on "I" being in the 40 to 50 range)

V' = 1.0

Roads are assumed to be 25 feet wide (3.03 acres/mile)

County	I	C	Miles	Acres	Emissions ton/yr
ALA	47	0.15	180.7	548	44
ALP	47	0.05	212.1	643	17
AMA	38	0.05	893.7	2708	59
BUT	47	0.05	875.3	2652	71
CAL	47	0.07	983.5	2980	112
COL	47	0.01	129.0	391	2
CC	47	0.10	55.2	167	9
DN	47	0.05	487.9	1478	40
ED	38	0.02	433.1	1312	11
FRE	47	0.25	253.4	768	103
GLE	38	0.01	607.5	1841	8
HUM	47	0.05	740.6	2244	60
IMP	47	4.45	427.0	1294	3085
INY	47	1.50	1951.8	5914	4753
KER	47	0.50	701.4	2125	569
KIN	47	0.32	259.8	787	135
LAK	47	0.05	518.0	1570	42
LAS	56	0.07	849.4	2574	115
LA	47	0.45	1194.6	3620	873
MAD	38	0.10	874.6	2650	115
MRN	56	0.05	76.9	233	7
MPA	56	0.05	601.4	1822	58
MEN	56	0.05	934.7	2832	90
MER	47	0.50	175.7	532	143
MOD	56	0.15	1885.1	5712	547
MNO	47	0.50	1508.6	4571	1225
MON	47	0.15	449.0	1360	109
NAP	47	0.05	42.2	128	3
NEV	56	0.05	575.1	1743	56
ORA	56	0.11	239.8	727	51
PLA	38	0.02	823.0	2494	22
PLU	38	0.05	3452.1	10460	227
RIV	47	2.47	1091.2	3306	4376
SAC	47	0.14	44.4	135	10
SBT	47	0.05	112.2	340	9
SBD	47	4.15	2103.3	6373	14171
SD	47	0.33	1362.5	4128	730
SF	56	0.05	108.0	327	10
SJ	47	0.30	37.7	114	18
SLO	47	0.13	543.3	1646	115
SM	56	0.05	58.5	177	6
SB	56	0.15	492.6	1493	143
SCL	47	0.06	254.8	772	25
SCR	38	0.11	58.1	176	8

SHA	38	0.05	2424.6	7347	159
SIE	38	0.05	1151.0	3488	76
SIS	47	0.05	4415.1	13378	358
SOL	47	0.20	6.9	21	2
SON	56	0.05	87.8	266	8
STA	47	0.35	27.7	84	16
SUT	47	0.05	95.0	288	8
TEH	38	0.05	1035.9	3139	68
TRI	38	0.05	2840.0	8605	186
TUL	38	0.06	685.0	2076	54
TUO	47	0.05	1757.7	5326	143
VEN	47	0.11	347.5	1053	62
YOL	47	0.03	53.5	162	3
YUB	47	0.04	381.5	1156	25
			--Miles--	--Acres--	--ton/yr--
	TOTALS		44968	136253	33549

Statewide total ton/day = 92

1) Guideline for developement of Control Strategies in Areas with Fugitive Dust Problems, U.S.EPA, October 1977, EPA-450/2-77-029.